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ABSTRACT

This publication, part 1 of two parts, presents the narrative materials for the teaching of the concept--the development of atomic energy and its social implications--growing out of a study made to determine the feasibility of teaching scientific concepts related to the social and historical developments of science and selected concepts related to atomic energy. In part 1, section 1 includes six chapters related to the development of faith in science by society, beginning with an introduction to nuclear energy, scientists, and society through a presentation of the history of science into the 20th century. Section 2 includes chapters 7-10 and relates to scientism, or what the author describes as excess faith in science by society. The publication includes a statement of focus for the research project as well as an abstract of the study. (EB)

Practical Paper No. 303 (Part 1 of 2 Parts)

THE FEASIBILITY OF TEACHING SCIENCE VIA A SOCIO-HISTORICAL APPROACH

Part II
Classroom Materials

by
Michael Lawrence Agin

Report from the Project on Elementary Science--Man and the Environment

Milton O. Pella
Principal Investigator

Part I, the report of the research, has been published as Technical Report No. 303

Wisconsin Research and Development Center
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STATEMENT OF FOCUS

Individually Guided Education (IGE) is a new comprehensive system of elementary education. The following components of the IGE system are in varying stages of development and implementation: a new organization for instruction and related administrative arrangements; a model of instructional programing for the individual student; and curriculum components in prereading, reading, mathematics, motivation, and environmental education. The development of other curriculum components, of a system for managing instruction by computer, and of instructional strategies is needed to complete the system. Continuing programmatic research is required to provide a sound knowledge base for the components under development and for improved second generation components. Finally, systematic implementation is essential so that the products will function properly in the IGE schools.

The Center plans and carries out the research, development, and implementation components of its IGE program in this sequence: (1) identify the needs and delimit the component problem area; (2) assess the possible constraints--financial resources and availability of staff; (3) formulate general plans and specific procedures for solving the problems; (4) secure and allocate human and material resources to carry out the plans; (5) provide for effective communication among personnel and efficient management of activities and resources; and (6) evaluate the effectiveness of each activity and its contribution to the total program and correct any difficulties through feedback mechanisms and appropriate management techniques.

A self-renewing system of elementary education is projected in each participating elementary school, i.e., one which is less dependent on external sources for direction and is more responsive to the needs of the children attending each particular school. In the IGE schools, Center-developed and other curriculum products compatible with the Center's instructional programing model will lead to higher morale and job satisfaction among educational personnel. Each developmental product makes its unique contribution to IGE as it is implemented in the schools. The various research components add to the knowledge of Center practitioners, developers, and theorists.

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ABSTRACT

The purpose of this study was to determine the feasibility of teaching science via a socio-historical approach utilizing selected concepts related to the social and historical developments of science and selected concepts related to atomic energy. The criteria used to assess the success of the approach were:

1. A significant increase in subject matter knowledge possessed by the students participating in the study.

2. A high level of student interest toward the socio-historical approach as indicated by the responses of the students to an interest questionnaire.

3. An increase in student understanding of knowledge related to

a. science and scientists,

b. science-society interrelationships, and

c. the atom and atomic energy.

The instructional materials for the study included a) 12 chapters of textual materials developed by the

investigator, b) a test based on the text, c) a series of slides, and d) four selected motion picture films. The investigator, who utilized a lecture-discussion technique with an accompanying slide presentation, taught the instructional unit to two different high school populations during two 14-day periods of instruction. The populations included in the study included 107 twelfth-grade students in American Problems classes (School A) and 76 tenth-, eleventh-, and twelfth-grade students in Chemistry classes (School B).

A 90-item multiple choice test, administered as a pretest and posttest to both groups, yielded three subtest scores--science and scientists, science-society interrelationships, and the atom and atomic energy--and a total score for each student. Mean gains--the difference between pretest and posttest class mean scores--for the subtests and total test were tested statistically and found to be significant for both schools. Correlation coefficients of individual scores on the test and IQ did not reveal any consistent pattern of relationship.

Student responses to a questionnaire indicate that a majority of the students in both schools expressed a positive opinion toward the interest producing potential of the unit and indicated that the reading material was at least at the same level of difficulty as material experienced in science classes. In addition, at least 83% of the students of School A and 91% of School B felt that the unit increased their understanding of a) science and scientists,

b) science-society interrelationships, and c) the atom and atomic energy.

On the basis of the conditions of the study, namely the procedures utilized and the nature of the populations included, it was concluded that teaching via a socio-historical approach is feasible since the performance of the students met the criteria for acceptance.

THE DEVELOPMENT OF ATOMIC ENERGY AND ITS SOCIAL IMPLICATIONS

SECTION I.

THE DEVELOPMENT OF FAITH IN SCIENCE BY SOCIETY

CHAPTER I. AN INTRODUCTION TO NUCLEAR ENERGY, SCIENTISTS, AND SOCIETY

Nuclear Energy Power Plants

Millions of Americans light their homes and power their appliances with electricity converted from nuclear energy. Many regions of the world are using electricity produced by nuclear energy power plants. These facilities are usually identified by a dome-shaped structure and no smokestack or smoke.

A nuclear power plant is similar to a conventional power plant in that each type uses steam to drive a turbine generator which produces electricity. The heat energy of steam is changed to mechanical energy in the turbine generator, which in turn changes the mechanical energy into electrical energy, or electricity. The important difference is the origin of the heat energy.

How is the heat produced? Conventional power plants burn fossil fuels--coal, oil, and gas. The combustion of these fossil fuels supplies the heat energy that is used to boil water to form steam. Nuclei of atoms undergo fission; they break into pieces. The fission reaction generates heat (by mass being converted into energy) and this heat is transferred to the water, changing it to steam. It can be said that the fission reaction in a nuclear plant serves the same purpose as the burning of a fossil fuel in a conventional plant--the generation of heat.

Nuclear fuel, however, has one big advantage over fossil fuel; it is more compact. The nucleus of an atom is the most concentrated source of energy known. One ton of nuclear fuel has about the same fuel value as three million tons of coal or twelve million barrels of oil. This means that it can be transported easily and at less cost.

Applications of Nuclear Power Plants

A unique characteristic of a nuclear reactor is its geographic independence; it can be installed in remote regions. The United States operates a nuclear plant at McMurdo Sound, Antarctica. This barren region does not have available fossil fuels as a source of power. A portable plant supplies heat and electricity to the research facilities at this polar station. The plant was built in the United States, shipped as prefabricated sections, and reassembled at Antarctica. This plant has proved to be a practical source of heat and electricity for this remote and isolated locality.

Some countries do not have large supplies of fossil fuels and others have ample supplies but they cannot supply distant regions. Consequently they have a shortage of electricity to power machines and other industrial equipment. This shortage of electrical power limits industrial and national growth of many of these nations, leading them to consider the use of nuclear fuels as a substitute for fossil fuels.

India is one country that uses nuclear power to generate electricity in regions that are great distances from sources of fossil fuel. Electricity is being produced in regions where agricultural and industrial opportunities were previously limited. India's long-range plans include a greater use of nuclear energy She possesses deposits of ore containing nuclear fuels, which enhances her plans for the future.

Israel is an excellent example of a country which lacks natural resources. She does not have an adequate supply of water, or the resources to get it. The Israelis have built an electricity-producing nuclear power reactor in the Negev desert. The electricity is used to pump water for irrigation into this desert, converting a once barren area into a green oasis. Perhaps nuclear energy will be used to convert the Great Sahara or Arabian deserts into green and productive oases. Nuclear energy may also permit modern cities to be built in regions remote from existing sources of power; perhaps the moon or even other planets.

Social Importance of Nuclear Energy

Nuclear energy is derived from nature. Like chemical combustion, it is another means for man to do work regardless of whether it is in the interest of science, commerce, recreation, or war.

The investigations leading to the discovery of nuclear energy and developments for its utilization are due to the dedicated work of an international array of scientists. For example, scientists from Europe, the United States, Japan, and other parts of the world have contributed to the development of nuclear science. However, the work of these scientists depends upon the cooperation of not only engineers, businessmen, and technologists, but upon entire populations of countries.

In order for the development of nuclear energy to be possible, the scientist must have the financial support of a national government which means he must have the support of people. Nuclear energy research is <u>scientifically</u> important but many of our citizens do not feel that financial support is necessary, a fact which also makes nuclear research socially important. The scientist needs the support of society but he in turn has a responsibility to society. The scientist is becoming more aware of his role in society. Are we aware of the role of the scientist? The study of nuclear energy and its social implications are excellent opportunities to look at the relationship between scientist and government, or more generally, between scientist and society.

An Invitation to Think

This unit will require you to think. It deals with the study of the scientist and his relationship to society. It will trace the place of the scientist in society through selected eras in history. The concept of the atom will also be traced. The scientist and the atom are being traced together because their historical backgrounds are similar and both have become important social influences during the last few decades.

The development and application of nuclear energy will be used as an example of the problems that the scientist and society can cause. Also considered will be the role that the scientist has played in promoting governmental support for the research in nuclear energy and the concern he has exhibited for its applications.

The social implications caused by scientific developments such as nuclear energy is an important aspect you will have an opportunity to consider. The scientific investigation and utilization of nuclear energy has political, military, economic, sociological, and biological implications for the livelihood of society. The Atomic Age has changed the strategies of warfare and the conditions of peace.

Future plans for nuclear energy have created a need for new materials, work skills, and techniques to solve the problem. Problems that radioactivity may cause for future generations must be considered. What are the benefits and what are the risks? No one is certain of the answer but we cannot ignore this and other questions. The scientist and society have been weighing the benefits and risks of nuclear power since its introduction during World War II.

The Scientist

His Position in Society

The scientist holds a special position in our society; he is on display. It is difficult to read a newspaper, listen to the radio, or watch television without seeing or hearing something about scientists. He is advisor to the President and witness before Congressional committees. He frequently announces new and often exciting discoveries. However, the relationship between the scientist and society has varied throughout history. Social involvement of the scientist has changed with time; he has been perceived differently by different societies. Social values, religious beliefs, prejudices, and even superstitions have influenced the scientist and his thinking. In turn, the scientist's contributions have had social and economic influence on society. England became a great sea power because her scientists contributed much to the study of navigation, while Germany became a leading industrial nation by nationalizing her science.

Problems of the Scientist

If we had lived in Ancient Greece what scientific problems would we have studied? Most likely we would have studied problems pertaining to nature. We would have started our investigations where previous generations had stopped. The modern scientist also studies nature; his investigations are a continuation of the work of previous generations. The scientist does not possess greater intelligence or greater powers of imagination than the scientist of antiquity but he does possess a greater amount of scientific knowledge. All scientists, past and present, have a common goal: to make nature more understandable. The scientist makes observations and attempts to form generalizations about nature. These observations often lead him to make inaccurate generalizations about nature. But each generalization has, in some way, been a contribution to the total body of scientific knowledge.

Methods of the Scientist

The scientist uses many approaches to the study of nature. Contrary to popular belief, there is not one scientific method but many equivalent and unrelated pathways to the study of nature. Science is in a sense practiced by everyone. When people try to explain things that they have observed they are acting like scientists. Every individual studies and explains his observations in different ways. If you were Isaac Newton, how would you have explained an apple falling from a tree?

Classes of the Scientist

When one studies science, he is confronted with the terms <u>pure</u> and <u>applied scientist</u>. Who is a pure scientist and who is an applied scientist? This is a difficult question. Galileo was an applied scientist when he developed the telescope but a pure scientist when he used it to learn more about nature.

The pure scientist has been viewed as being concerned with the study of nature for the sake of knowledge, whereas the applied scientist has been associated with the application of scientific knowledge for practical purposes. One science historian states:

> necessity is the mother of invention, or technology [applied science] and curiosity is the mother of pure science. (1-1)

In a very strict sense, the development of an atomic theory would be the work of a pure scientist and its utilization would be associated with an applied scientist. However, it is difficult to divide the scientist into separate categories; his activities are interrelated and interdependent. Numerous discoveries of pure science have become useful and practical tools for society and there are many instances where applied science has uncovered new knowledge which was not applicable to the solution of practical problems but extended the knowledge of science. As one scientist stated in 1882:

> I often wish that this phrase "applied science" had never been invented. For it suggests that there is a sort of scientific knowledge of direct use, which can be studied apart from another sort of scientific knowledge, which is of no practical utility, and which is termed "pure science." <u>What people call applied science is nothing but application of pure science to particular</u>

> <u>classes of problems</u>. [italics mine] It consists of deductions from those general principles, established reasoning and observation, which constitute pure science. (1-2)

The applied scientist is often called a <u>technologist</u>. The activities of a technologist is <u>technology</u>, a field that includes the work of engineering and many kinds of investigations. The development of nuclear reactors for the utilization of nuclear chemistry is the work of technology and pure scientific research. However, the President's Science Advisory Commission states:

> We do not believe in any artificial separation between basic [pure] and applied research or between science and engineering. <u>The fact that a scientific advance is useful does not make it unscientific</u>. [italics mine] (1-3)

Patterns of Scientific Development

The scientist and the concept of the atom have undergone successive stages of development. This development has tended to follow a cyclic pattern. Like oceanic tides, science and the atom have had high and low periods throughout history. Each new cycle appears to be more socially prominent. It has been built upon the scientific knowledge of the previous cycles. We are living a portion of this history--a portion which is influenced by the past and will influence the future.

Imagine yourself sitting along the shore of the ocean of scientific history observing the incoming waves. Each wave is a different society in history with its own form of science and its own type of scientist. What are the people like? What do they believe? How does the scientist serve society's purposes? The actual dates that these societies existed are not important. What is important is the interaction of science and society. Our task is to study the ebb and flow of the tides of scientific history with the hope that the past and the present will help prepare us for the future. In other words, we will use science to study science.

CHAPTER II THE BEGINNINGS OF SCIENCE

The Roots of Science

When did science begin? No one knows because science was being practiced before man named or defined it. Science evolved through centuries of history. No matter how far archaeologists have gone back in pre-historic times they have not found a time when early man did not observe natural phenomena, speculating on its causes in his primitive way. Man has applied his acquired knowledge in devising and using new weapons, tools, and machines.

Science may be described as an organized social activity for describing and controlling the material world. As one social scientist states:

> Science is a social activity, a set of behaviors taking place in human society. (2-1)

This activity has its historical roots in two primary sources: (1) the technical tradition and (2) the spiritual tradition. These traditions existed before civilization appeared (judging from the development of tools used by the men of the stone age from their burial practices and cave paintings).

The technical tradition consisted of practical crafts and skills that were developed, improved, and handed on from one generation to the next. The making of flint tools is the first known craft--a skill which was discovered by creatures of a different species from ourselves. These early man-like creatures made rough flint weapons and tools out of bone and horn. They lived about one million years ago and left no indication of their mental abilities.

The spiritual tradition involved human aspirations and ideas. Pure science, when it did exist, was part of this tradition, whereas applied science was part of the technical tradition. The men who were caretakers of the spiritual traditions held special positions in their societies. Most of the early societies had schools for the training of these priestly administrators (often called scribes), but the crafts were transferred from artisan to artisan by word rather than by written instruction. Although science arose from these roots, the roots were separate entities until the 17th Century (A.D. 1600). The priest and the scribe were separated from the craftsmen. The rift which existed between the traditional and spiritual traditions is quite evident from this Egyptian papyrus of about 1100 B.C.

A father advises his son:

> Put writing in your heart that you may protect yourself from hard labor of any kind, and be a magistrate of high repute.

> The scribe is released from all manual tasks; it is he who commands. I have seen the metal worker at his task at the mouth of the furnace, with fingers like a crocodile. He stank worse than fish-spawn. I have not seen a blacksmith on a commission or a founder who goes on an embassy. (2-2)

Modern Man

Homo sapiens (modern man) appeared about fifty thousand years ago. He showed high intelligence but he had almost everything to learn. He was not handed a scheme for classifying plants, animals, and other objects; he had to invent one. By trial and error (or success) he classified plants into edible and poisonous categories.

Man invented and improved pictorial art. His drawings of bison and other animals indicate that he was making close observations of natural phenomena and also that he had some knowledge of pigments. He discovered fire and used it to light his caves. By domesticating animals and plants he was able to provide a more secure supply of food. This enabled him to change from a nomadic hunter to a member of a small established community. Dogs, cattle, goats, sheep, and pigs were domesticated just before the rise of the first known civilizations. Agriculture, one of man's most important innovations, dates back to about 3500 B.C. Most historians mention men as being the first farmers but the conditions of the time indicate that women were probably the first to take up the practice of farming. The women probably planted and cultivated various types of plants while the men were away hunting for food.

As time progressed man rapidly increased in skill. He made pottery and ornamented it with colors. He learned how to make cloth, mats, and baskets. He built huts to live in and traveled in boats with oars and sails. Some of his possessions were his carvings representing early hunting exploits or were crude statues of his gods. Early modern man had accomplished much but he was not considered to be civilized until about 3500 B.C.

Early Civilizations

Early man lacked: (1) a metal; (2) a form of writing; and (3) a national organization. His society was not considered a civilization. No one knows when the first civilization existed but three of the earliest existed about the same time in history. These three civilizations (about 4000 to 3400 B.C.) were confined to the valleys of the Nile, Tigris-Euphrates, and the Indus Rivers. They were dependent upon the rivers for fresh layers of fertile soil. Little is known about the Indus valley civilization, so we will confine our discussion to the Nile and

Tigris-Euphrates people.

Settled communities flourished in these valleys. Marshland was drained and deserts were irrigated so that large areas were under cultivation. The Egyptians settled along the Nile and the Mesopotamians (various historical groups such as Sumerians, Babylonians, and Assyrians) occupied the fertile Tigris-Euphrates valleys.

The scientific advancement of these societies did not steadily increase for the thirty centuries (3000 years) in which the Egyptian and Mesopotamian cultures continued to flourish. It would seem that the later years of science in these societies would be the most productive. However, the introduction of new ideas and products to these cultures reached a peak about 2400 B.C. Most of the later works were nothing more than minor alterations rather than innovative improvements. These two societies did make contributions to science and these contributions will be considered after a discussion of their living conditions.

Do you think that natural phenomena has an influence on the lives of people and how they think? Can it affect the practice of science? Keep these questions in mind as we consider the Egyptian and Mesopotamian societies and the accomplishments of their scientists.

Egypt

The Nile rises with predictable regularity every year. This probably gave the Egyptians a feeling of security; their future seemed certain and predictable.

To the Egyptians the universe appeared to be a box--the earth at the bottom and the sky at the top. They believed that the sky was supported by four mountain peaks at the four corners of the earth. The Nile flowed south through the middle of the earth after it had branched from a universal river that flowed across the earth. The Egyptians believed that the universal river was almost as high as the sky and that it carried the boat of the sun-god on his daily journey across the sky. The boat always kept as near the earth bank as possible. At the time of the Nile flood, the sun could come closer to the earth than in the winter, which accounted for the seasonal changes of the sun's position.

The world was thought to have come into being from primeval chaos of the waters. The heavens, earth, air, and other natural objects and forces were considered to be personal gods. These gods came into being by the union of male and female gods of chaos. However, the younger gods worked toward the ordering of the universe. They used magic spells and words of command to bring about order.

Egyptian society reflected the belief in the certainty of the future and the ordering of nature. The Egyptians did not conceive of battle or physical force as a world-ordering process--their gods were powerful without being violent. The rule of kings and the control of nature was considered certain. The dynasties of Egypt were long-lived and their governments followed a definite legal code. Contrast this with the Mesopotamian society.

Mesopotamia

The Tigris-Euphrates' floods were unpredictable. They were feared rather than welcomed and the future seemed uncertain to them. A need for prediction existed.

These people believed that the earth was a flat disc. The heavens was considered to be a hemi-spherical vault or dome resting upon the water that surrounded the flat earth. Above the heavens was more water and beyond this the home of the gods. The sun and the other heavenly bodies were gods who left their dwellings daily and travelled across the immobile dome. The Mesopotamians believed that the gods controlled earthly affairs. The motions of the heavenly bodies were believed to predict the destiny the gods were planning for man on earth.

The Mesopotamian creation myth was similar to the ideas of the Egyptians but the Mesopotamians placed a greater emphasis on the chaos of nature and the battle of younger gods to tame it. They viewed the unpredictable floods as chaos regaining advantage over the gods of control. They believed that flint flaked when struck because it was being punished for a transgression against the gods.

In Mesopotamia there arose battle kings or city governors. The cities fought for land and the battle kings governed by the force of arms. The dynasties of kings were short-lived; their rule was uncertain and arbitrary. The control of the forces of nature in Mesopotamia was uncertain, so these people resorted to occult methods of determining the course of future events. Two occult methods are known as astrology (later horoscoping) and hepatoscopy (making predictions from the study of the liver of sacrificial animals).

Now let's look at the contributions of Egyptian and Mesopotamian scientists.

Science in Egypt and Mesopotamia

The accomplishments of early science do not seem very impressive. But when you consider what prior knowledge these people had, their accomplishments are astonishing. The Egyptians and Mesopotamians made several contributions necessary for scientific advancement.

What did these early civilizations contribute to science? They contributed:

1. The tools, metals, writing, and writing materials necessary for the future discovery and recording of scientific fact;
2. The beginnings of mathematics;
3. The beginnings of astronomy; and
4. The beginnings of medicine and surgery.

A brief look at these two civilizations will reveal that they possessed many similarities. This is expected because they did have knowledge of each other. They also knew about each other's accomplishments. They both used copper and later the tin-copper alloy called "bronze." They both studied the heavens, had some form of mathematics, made fairly accurate calendars, and had some form of medical practice. However, many of their results were derived by different methods and through the observation of different natural phenomena. We will discuss these two civilizations together so that we will have a chance to compare their science.

Tools

These two civilizations were the oldest known makers of metallic tools. They smelted copper ore by heating it with charcoal. The nuggets produced were forged into tools that enabled man to improve his surroundings. Later, copper and tin were heated together to form the alloy "bronze." The metal-smith formed the tools which elevated the carpenter's and the stonemason's activities into skilled crafts. The use of copper and bronze tools enabled these craftsmen to work other materials. Egyptian tombs have inscriptions that depict these types of workers and materials. Some of the tombs also have cloth and metallic relics with the mummified bodies.

Mathematics

Both cultures had a form of mathematics but the Mesopotamian mathematics was much more advanced. They originally started with the base 10 (ten figures), later they went to the base of twelve (divisible by 1, 2, 3, 4, and 6), and finally to a base of sixty (divisible by 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, and 30). They had knowledge of the theorem of Pythagoras, they had tables for square roots, cube roots, and they even had interest tables (25 to 33 1/3 percent was the interest rate at that time).

The Egyptians used a base ten system before 3000 B.C. They used individual strokes to indicate the units of ten which made their mathematical calculations very difficult. The Egyptians had a yearly problem of relocating boundaries of land parcels along the Nile so they developed and perfected a system for surveying land. This system of measurement and calculation was a forerunner of geometry. The supreme testimony of the ability of the Egyptians to use mathematics and surveying is their architecture. The Great Pyramid, built about 2800 B.C. as a king's tomb, is an example. Its sides are about 750 feet long and differ by about one inch. The angle deviation from ninety degrees is less than one degree. This precision indicates that the craftsmen were assisted in their pyramid-building by architects and mathematicians.

Writing

The invention of writing was one of the foundations of science. Knowledge that passed from the old to the young by word of mouth remained scanty and unreliable. Writing enabled man to pass his thoughts on to later generations with greater reliability. However, the Egyptian and Mesopotamian writing systems contained many characters making them very complicated. The only ones who knew how to read were the scribes; therefore, they had a monopoly. All learning remained in their control. The Egyptian or Mesopotamian scribe was not simply a clergyman but he was the man of learning and the man of god in one, a combination common among primitive people. The architect, medical man, mathematician, and supervisor of metal workers were priests. The temples they used were built not only as churches but as libraries, observatories, and workshops. From these temples the priestly scribes controlled the people.

Astronomy

The Mesopotamian scribe used the study of the heavens to make a calendar. This calendar had religious as well as practical purposes. Yearly events such as seedtime and harvest were usually associated with religious festivals.

As the Tigris-Euphrates flooding did not occur with yearly consistency, they had to rely on the heavens, in particular the moon, for the development of time units. They had twelve lunar months (about 29½ days each--a total of 354 days). This was not equal to a full year so the Mesopotamians added an extra month when their calendar and the seasonal agricultural festival times were not in agreement. In addition to the unit of the lunar month, they gave us the names of the days of the week (named after the sun, moon, and the five known planets). They divided daylight time into 12 hours, the hour into 60 minutes, and the minute into 60 seconds. All this work took place before 2000 B.C.!

The Mesopotamian's spiritual beliefs made them close observers of the heavens. They were preoccupied with what is known today as astrology or the prediction of natural and human events from the movements of celestial bodies. Because of their astrological beliefs, they left numerous astronomical records. They gave the constellations their names and divided the heavens into twelve parts or zones. These zones comprise what is known as the zodiac.

Mesopotamians were responsible for accurate records of the motion of moon and several planets. They knew that the sun, moon, and earth were aligned once every 18 years. Thus, their ability to predict the eclipse of the moon, an event that happened every 18 years.

The Mesopotamian scribe (or scientist) was responsible for making predictions about events. If he predicted an event for his king and it did not occur he was not seriously criticized. But if an event took place (especially an eclipse) without his prediction he was in serious trouble. The people relied upon the scribe to explain his observations. All observations were explained as works of the gods because all Mesopotamian science was based on the assumption that all life was under the power of the gods. The following quotes translated from ancient writings is a good example of the work of the scribe.

REPORT OF BABYLONIAN-ASTROLOGERS

When Jupiter goes with Venus, the prayer of the land will reach the heart of the gods. Merodach and Sarpanitum will hear the prayer of thy people and will have mercy on thy people.

Let them send me an ass that it may ease my feet. From Nirgal-itir.

REPORT OF A PREDICTED ECLIPSE WHICH THE OBSERVER THINKS MAY NOT HAVE IN FACT OCCURRED

To the king of countries, my lord thy servant Bilusur (?) May Bel, Nebo and Samas be gracious to the king my lord. An eclipse passed the city of Assur, wherein the king is dwelling; now there are clouds everywhere so that whether it did or did not happen we do not know. Let the lord of kings send to Assur, to all cities, to Babylon, Nippur, Erech and Borsippa; whatever has been seen in those cities the king will hear for certain. The omens (?)...the omen for an eclipse happened in Adar and Nisan; I send all to the kings, my lord, and they shall make a nambulbi-ceremony for the eclipse. Without fail (?) let not the king omit (?) to act rightly. The great gods in thy city wherein the king dwells have obscured the heavens and will not allow the eclipse; so let the king know that this eclipse is not directed against the king, my lord, or his country. Let the king rejoice.... (2-3)

The Egyptians accomplished as much in astronomy as the Mesopotamians because they had the flooding of the Nile to give them a reliable point of reference. Some science historians believe that the Egyptians originally used the average time between the rising of the Nile to determine the length of a year. However, it is known that later Egyptian astronomers used the helical rising of the "Dog Star" (Sirius) as a more precise point of reference. The "Dog Star" rises just before the sun about every 365 days and closely coincides with the rise of the Nile. Therefore, the Egyptians were aware that the year consisted of about 365 days. Their year was divided into 36 ten-day periods and five extra days for holidays. The astronomical contributions of the Egyptians are not well-known because they left no records and their astronomy was not well-developed.

Medicine and Surgery

The demand for the sick to be healed is the same today as it was in the past. This demand has always been greater than the powers or techniques of the healer. Throughout history two methods have been used: (1) healing by mental means (magic, spells, dream-interpretation) and (2) healing by physical means (drugs, baths, diet, and the knife). Frequently, both were employed simultaneously. One science historian states that as physical medicine and surgery become effective the art of mental healing is used less. This point holds true for all aspects of life: the more understanding we have of a phenomenon or object, the less likelihood of explaining it by using superstition or myth.

The Egyptians were more able in the field of medicine. Some very sound surgery was practiced in Egypt about 3000 B.C. A 700 B.C. medical papyrus pertains to the works of Imhotep, a physician and minister to King Zoser (about 2980 B.C.). Imhotep is considered the founder of Egyptian medicine. This and other scrolls give precise and well-founded instruction for treating certain fractures, wounds, and dislocations. It carefully distinguishes between ailments which may be treated from those that are fatal and should be left alone. The cases were classified as favorable, uncertain, and unfavorable (or incurable and not to be treated).

The following is a translation of a 1500 B.C. medical papyrus of unknown authorship. It advises:

EGYPTIAN SURGICAL CONCERNING BROKEN NOSES

> 1. If thou examinest a man having a break in the chamber of his nose, (and) thous findest his nose bent, while his face is disfigured, (and) the swelling which is over it is protruding thou should say concerning him: "<u>One having a break in the chamber of his nose. An</u>

ailment which I will treat."
Thou shouldst force it to fall in, so that it is lying in its place, (and) clean out for him the interior of both his nostrils with two swabs of linen until every worm of blood which coagulates in the inside of his nostrils comes forth. Now afterwards thou shouldst place two plugs of linen saturated with grease and put into his two nostrils. Thou shouldst place for him two stiff rolls of linen, bound on. Thou shouldst treat him afterwards with grease, honey, (and) lint every day until he recovers.

2. If thou examinest a man having a smash in his nostril, thou shouldst place thy hand upon his nose at the point of the smash. Should it crepitate under thy fingers, while at the same time he discharges blood from his nostril (and) from his ear, on the side of him having the smash; it is painful when he opens his mouth because of it, (and) he is speechless.
Thou should say concerning him: "One having a smash in his nostril. An ailment not to be treated." (2-4)

Unsuccessful physicians and surgeons were often heavily fined or lost a hand. So you can see the precautions.

Little is known about the medical practice in early Mesopotamia. However, a legal code by Hammurabi of Babylon (ruler about 2000 B.C.) prescribed a fee of two to ten shekels for a successful operation (a craftsman received about ten shekels a year) while an unsuccessful surgeon was to have his hands cut off. The Mesopotamian's excelled in spells and magic, whereas the Egyptians seemed to excel in physical medicine.

Medical texts of Egypt and late Mesopotamia discuss the demon theory of disease. Illness was personified as an evil spirit that physicians sought to expel. The expulsion could be attempted by magic incantations, spells, or the use of emetics, purges, or harsh medicinal ingredients to put the demon to flight. Earliest Egyptian medical texts listed drug recipes for different diseases. A medical papyrus from about 1600 B.C. gives symptoms, diagnoses, and prescriptions for the treatment of 47 diseases. Later texts are more magical in character. They describe how the illness can be diagnosed by observing certain omens and how to treat the patient by drawing off the demon and burning it. In ancient times many of the drugs and procedures were useless and possibly harmful. So the patient treated by magic spells was often better off in the hands of nature than a patient treated by drugs or manipulations.

Other Civilizations

As far as science historians know, the Egyptians and Mesopotamians were by far the most advanced peoples of the years 4000 to 600 B.C. Very little is known about India and China during this time. In the years between 2000 and 600 B.C. many other centers of civilization derived their culture partly or completely from Egypt and Mesopotamia. The Cretans, Phoenicians, and Jews are examples. But none of these seem to have made noteworthy contributions to science.

Summary

The two civilizations reached their cultural peaks about 2400 B.C. after which they began to decline. The late Bronze Age had few inventions. The alphabet and iron works evolved from people removed from these two civilizations. The Egyptians and Mesopotamians did not have the alphabet script and iron for their use. But later civilizations utilized these two to their advantage in the pursuit of science.

Some science historians feel that the separation of the craftsman and the scribe was one reason for the decline of science and culture in Egypt and Mesopotamia. The craftsman practiced his art and communicated his skill to his successor. He was preoccupied with his craft and did not give any thought to anything other than the improvement of his art.

The scribe recorded observations for practical reasons but did not attempt to explain the things he observed. He was content with the myth that gods were responsible for all observed events and objects.

Later, the scribe became increasingly dependent upon the written words of his predecessors. Rather than make predictions from his own observations, he based all his predictions on earlier works, often tending to glorify the works of his predecessors. This attitude was not conducive to the advancement of science because there was no chance for new discoveries. Rarely were they concerned with the study of nature that preoccupied later civilizations.

In the next chapter we will consider science that was concerned with speculations and explanations about natural phenomena. The scientist (or natural philosopher) was concerned about nature for the sake of knowledge rather than for practical purposes.

CHAPTER III. GREEK SCIENCE

For many years science historians have marveled at the sudden rise of science during the time of the Ancient Greeks. The Greek scientific tradition (believed to have begun in the Greek Ionian colonies about 600 B.C.), is often referred to as the "Greek Miracle." However, recent archaeological discoveries in Asia Minor indicate that the Greeks built their science upon knowledge received from other Near Eastern cultures. Evidence shows that Greek science is a continuation of Egyptian and Mesopotamian science. In spite of these new findings, the period of Greek science represents a time of great advance in science. The Greeks added new methods to scientific thought and asked questions that we are trying to answer today.

Factors That Influenced Greek Science

A question often asked is "Why were the Greeks able to speculate and not other people of this time?" No one is certain of the answer but the "freedom of thought" enjoyed by the leisure class along with the following factors probably contributed much to their accomplishments. Most evidence indicates that the Greeks enjoyed a real "spirit of freedom." One exception is Sparta which was a militaristic city-state where the citizens were always training for war. The people of Sparta led a more restricted life than the people of Athens or Miletus. It is interesting to note that Sparta probably contributed the least to the advance of Greek science.

Humanized Superstitions

We cannot hope to discuss all the developments leading to the "Greek Miracle" but we can consider several factors that influenced the Greeks. The Greeks, for example, were less dominated by supernatural powers. The taboos and superstitions of the Bronze Age did not restrict their activities. They believed in a form of mythology in which their gods were humanized. The Greeks respected their gods but they found humor in the activities of the gods. Who but the Greeks would have an intoxicated god of wine (Bacchus) riding around on a donkey?

Alphabetic Writing

The Greeks made tools and weapons of iron which they used to build their civilization. But of more importance to science was their use of alphabetic writing. The alphabet--believed to have been developed by the Phoenicians about 1200 B.C.--made writing easier to understand than previous writing systems. Adoption of alphabetic writing by the Greeks made possible a wider distribution of learning than prevailed in Egypt and Mesopotamia. It did not start a revolution in the education of the people but it did remove writing and reading from the absolute control of the scribe or priestly class.

Commerce

The Greeks were sea-going people who enjoyed commercial sea travel. They had the traveler's feel for space and spatial relations--a factor often absent from agricultural communities of pre-Grecian times. Their travels placed them in contact with many communities and they were able to observe the traditions and obtain the knowledge of various cultures. This permitted them to choose what they felt was valuable and reject the rest. Many cultures probably donated something to the Greek culture but no outside culture dominated the early Greeks.

Political Structure

The Greeks had a simple form of government in which they practiced a modified form of democracy within a series of city-states. Each city-state or <u>polis</u> was independent of the other city-states and determined its own rules and regulations. The Greek political structure was not a total democracy because all citizens did not belong to the same class. The Greek society was divided into a leisure and a slave labor class. Work done with the hands was delegated to the slave labor class. This left a segment of the population with a large amount of leisure time. The Greek word for leisure is schole, so a man of leisure was called a scholar. The scholars, with much time on their hands, could divert some of their attention toward questions concerning nature. As they asked themselves questions they began to speculate about possible answers. These speculations gave rise to a new type of scientific activity.

Experimentation

The Greeks integrated their political simplicity with knowledge acquired by travel to develop an impressive scientific tradition. However, their dislike for manual labor was reflected in their scientific activities. Ancient Greek science, which was primarily an intellectual activity of the leisure class, was generally a mental activity with little or no experimentation. Their attitude toward experimentation gradually changed, but it was never very popular among the Greeks.

Greek Versus Egyptian and Mesopotamian Science

There was no complete break from science in the past but the Greeks provided new and fertile ground for the growth of science and scientific ideas. According to Plato, the Egyptians had no love of knowledge as did the Greeks; Egyptian affection was for riches and material property. Egyptian science was empirical; they accumulated masses of particular and isolated facts but never gave thought to letting one fact point to another. To the Egyptians, knowledge was a matter of revelation, a gift from the gods. Man was not to discover what was not revealed.

The Babylonians were influenced by their astrological success. This encouraged them to perfect the lucrative art of foretelling the astronomical future. However, little is known about their trying to increase their knowledge from the standpoint of sheer intellectual curiosity. They used their knowledge primarily for astrological gain.

One science historian seems to summarize the difference between Greek and earlier science when he states:

> The organized knowledge of Egypt and Babylon (part of Mesopotamia) had been a tradition handed down from generation to generation by priestly colleges. But the scientific movement which began in the 6th Century among the Greeks was entirely a lay movement. It was the creation and the property, not of priests who claimed to represent gods, but of men whose only claim to be listened to lay in their appeal to the common reason of mankind. More generally, it was perhaps the special kind

> of <u>intellectual curiosity</u> which impels men to try to <u>understand</u> rather than <u>merely to know</u>. (3-1)

The Study of Matter

The Greeks studied many aspects of nature. These studies were the forerunners of biology, chemistry, physics, and mathematics. They also began something more important; they started the tradition of speculation in science. The Greeks were the first theoretical scientists. They observed their environment and started to ask questions. One question that was started by the Greeks of Ionia has become a basic problem of speculation for all succeeding generations. The question, stated very simply is, "What are all things made of?" This question has been debated since the time of these early Greeks.

Matter is Continuous

The question of the nature of matter over the centuries has been answered by two opposing points of view: (1) matter is continuous and (2) matter is discontinuous. Anaxagoras (C. 488-428 B.C.) was an early champion of matter being continuous. He argued that if you took a bit of matter (for example, a nugget of gold) cut it in half, and then cut the half in half and so on, you would never end your cutting. He could not see any end to matter because he could not see an end to this halving process. It seemed to him that matter must be continuous and infinitely divisible (theoretically). He found it impossible to conceive that matter could be made up of discrete building blocks.

Matter is Discontinuous

In the 5th Century B.C., the halving process was about the extent of man's ability to probe into the physical nature of things. This was indeed a handicap to the progress of Greek science. However, out of this same scientific atmosphere came a view of matter that was quite revolutionary. This bit of incredible speculation was not understood by most Greek scientists because it was too revolutionary for the times. Democritus (C. 460-370 B.C.) was the first scientist to clearly present this point of view. He viewed a sandy beach from a distance and noticed that it looked like a solid mass of material. He knew the beach was composed of millions and millions of sand grains. Then an idea came to him. He thought, "Perhaps each sand grain could also be composed of smaller pieces of matter and that eventually the pieces of matter could not be sub-divided." His idea was that all matter is made up of minute particles or that matter was discontinuous. These particles, said Democritus, were the ultimate in matter. They were, in his native language, a-tomos: not cutable. Thus, the name and idea of the atom were born.

The idea that matter is composed of atoms--fundamental to the study of atomic energy--started with the Ancient Greeks. But it is only one of many ideas about the nature of matter presented by the Greeks. As we look at the history of Greek science we will consider some of the ideas about matter that have influenced the thinking of scientists.

Periods of Greek Science

The characteristics of Greek science changed during its one thousand years of existence. This change in character, along with a shift in centers of scientific activity, has enabled science historians to separate Greek science into separate periods. It is often divided into four chronological divisions. The first division or period is usually called the pre-Socratic period (C. 600-400 B.C.). The second is the 4th Century (C. 400-300 B.C.). This is the time when Plato and Aristotle made their influencial contributions. The third period, which is called the Hellenistic Period (C. 300-100 B.C.), was the time of Greek cultural expansion following the conquests of Alexander the Great. During this period, the Greeks started to assimilate more of the older cultures, a factor which eventually changed Greek science. The Hellenistic Period was a great period in Greek science. It was the time of Euclid (C. 330-260 B.C.), Archimedes (C. 287-212 B.C.), and many others. The last is the Greco-Roman Period (C. 100 B.C. to A.D. 600)--a period during which Greek science was affected by religious and nonrational influences. Following the last period Greek science passed to the Arabs (about A.D. 800), then to the Latin West via the Arabs (about A.D. 1100). We will look at the first three periods in this chapter and consider the Greco-Roman Period in Chapter IV.

First Period: Pre-Socratic Greek Science

As previously stated, the Greek intellectual tradition became distinctly recognizable about 600 B.C. Its origin is unknown. Archaeologists believe that much of the Greek tradition was derived from a Minoan civilization which flourished on the island of Crete (3500-1500 B.C.). They are not certain however, because they cannot read the Minoan writing script. But pottery which has been excavated in Ionia indicates that early Greek communities existed during the Minoan era.

Herodotus (C. 484-425 B.C.) says that the 6th Century B.C. is the time when:

> The Greek race was marked off from barbarians, as more intelligent and more emancipated from silly nonsence. (3-2)

The assumed place of Greek origin is a colony called Ionia. It is part of what is Turkey today and is almost opposite the island of Crete. Ionia's largest city was Miletus (population about 10,000) and was a great center of commercial trade, especially with Egypt. Ionia eventually had about 60 daughter cities along the Mediterranean coast and these communities enjoyed a constant interchange of ideas with other Mediterranean countries.

The science of this period, as well as the next, was almost entirely theoretical; the Greeks did not have observatories and laboratories. The only equipment they had (besides writing materials) was their brain with which they attacked their various problems with a minimum of observation and a maximum of speculation. Their philosophical speculation about nature was different from science as we understand it today. We refer to these Greeks as scientists but they considered themselves to be "natural philosophers." We will look at some of these natural philosophers and how they speculated about the question, "What are all things made of?"

Thales

The beginning of Greek science is usually traced to the work of the philosopher Thales (C. 585 B.C.). He was of Phoenician extraction and lived at Miletus (a city in the Greek Ionian colony). His greatest contribution was to astronomy, which he derived partly from Mesopotamian sources. Thales took an active role in the practical affairs of his community. He also made a fortune in the olive market, a factor which enabled him to devote much leisure time to study and travel.

Thales traveled as a tourist and merchant to Egypt where he obtained knowledge of geometry, and to Mesopotamia where he studied astronomy. He must have come across the creation stories of Egypt and Mesopotamia because he proposed that water was the fundamental substance of nature. The earth, he supposed, was a cylinder or disc which floated on the water below, and the waters above were the source of the rains. In his philosophy and that of other Ionians, nature became more impersonal than it had been in Egypt and Mesopotamia. They considered heavenly bodies as solid material objects, not powerful personalized beings.

Anaximander

Anaximander (C. 611-547 B.C.), a pupil of Thales, took a different point of view. He believed in an unidentifiable primary substance. As one science historian states:

> He held that there was a primary substance, but it was not identifiable with a known substance. This primary substance was eternal, boundless, uncreated, and indestructible, and contained within itself all of the contraries, i.e., hot and cold, wet and dry. There was an eternal motion of the primary substance which brought about the separation of opposite qualities like hot and cold. The visible world thus resulted from this separation of contraries [hot-cold, wet-dry] with the subsequent union of principles having a harmony with one another, such as heat and moisture. (3-3)

Anaximenes

Fifty years after Thales, his direct successor, Anaximenes (C. 585-525 B.C.), took mist or air as his primordial substance and derived other elements from it. He believed that the various forms of matter changed into one another by the processes of condensation and evaporation. When water was evaporated it became air and when it was evaporated and heated it became fire. To Anaximenes, fire was heated air. He also believed that condensation of water produced earth. Thus, the four elements--earth, water, air, and fire were all modifications of one another.

Empedocles

While the Ionians were picturing the universe as something simple, the Pythagoreans and the Sicilian Empedocles (C. 490-435 B.C.) were advocating a more complex view of the world. Empedocles, influenced by the Pythagoreans, replaced the one fundamental substance of the Ionians with four distinct "elements"--fire, water, air, and earth. He taught that everything was formed of these four elements in different proportions.

The four elements were themselves formed by the attraction and repulsion of two contrasted qualities--hot and cold and wet and dry. Thus, there were four combinations:

	Dry	Wet
Cold	Earth	Water
Hot	Fire	Air

Empedocles taught that the universe had begun as a chaotic mixture of the four elements. First, air was separated out of the mixture, and then fire. These were succeeded by earth, from which water was squeezed out.

Leucippus and Democritus

The unit concept of matter (Empedocles' elements) was extended by the "atomists." Leucippus of Miletus (C. 470-400 B.C.) and Democritus (C. 460-370 B.C.) of Abdera were the early atomists. They believed that everything in the universe was composed of atoms that were physically indivisible. There were an infinite number of atoms and they traveled in an infinite void (space). The atoms existed from eternity; they had not been created and they could not be destroyed. Atoms, according to Leucippus and Democritus, differed in size, shape, and perhaps weight.

The atomist supposed that life had developed out of a primeval slime--man as well as animals and plants. Man was a microcosm of the universe for he contained every kind of atom. Life and soul were akin to fire for they were composed of small, spherical atoms.

Second Period: Greek Science of Athens (4th Century B.C.)

Athens did not flourish as early as the Greek communities in Ionia and Southern Italy. However, Ionia was conquered by the Persians (about 500 B.C.) and Athens inherited the trade with the Greek colonies along the Black Sea, previously serviced by the Ionians.

Politically, Athens commanded the leadership of the Greek cities against the Persians who were defeated in 490 B.C. at Marathon. After her victory, Athens entered upon a period of prosperity and greatness. Anaxagoras was brought to Athens from Miletus to add to the cultural life of the city. He brought the spirit of science westward to Athens. Among his disciples was Socrates (C. 469-399 B.C.) who was partly responsible for a change that was about to take place in Greek science.

The crafts of Athens flourished from the beginning of its founding. Solon (C. 639-559 B.C.) decreed that a son need not support his father unless the father taught him a trade. With a well-established crafts tradition and the importation of natural philosophy, it appeared as if Greek science was going to continue to grow into a healthy experimental science. But the population of Athens grew and the society became divided into classes; the crafts and philosophical traditions were forced apart. Two hundred years after Solon, Xenophon (C. 430-355 B.C.) wrote:

> The mechanical arts carry a social stigma and are rightly dishonored in our cities. For these arts damage the bodies of those who work at them... by compelling them to a sedentary life and to an indoor life and, in some cases, to spend the whole day by the fire. The physical degeneration results also in degeneration of the soul. (3-4)

Thus, experimental science was discouraged in its infancy. Natural philosophy, which used models derived from the mechanical arts, was dishonored. It was about this time that Athens and Sparta started a war which was to lead to the political downfall of Athens. The decline of Athens was witnessed by three men. Each man had an influence on later scientific thought.

Socrates

During the lifetime of Socrates, Athens experienced difficult times. She was defeated by the Spartans in the Peloponnesian wars (431-404 B.C.). The people tried to adjust to this defeat by turning their attention to man and society. Socrates considered the prime task of the philosopher was the ordering of man and human society and not the understanding or control of nature. He rejected natural philosophy (science) and concerned himself with problems of ethics and politics. According to Xenophon, Socrates considered astronomy 'a waste of time.' This was the state of affairs in Athens when Socrates' successors, Plato, and later Aristotle (C. 384-322 B.C.), came into prominence.

Plato

The work of Socrates was continued by Plato (C. 427-347 B.C.). He felt that there was a place for nature study in philosophy but that it was subordinate to ethics, politics, and theology. Plato extended the view of the Pythagoreans that the heavenly bodies were actually divine and noble beings and that their motions were perfectly uniform and circular. He gave his students the problem of determining the circular movements that would explain the motion of the heavenly bodies. But he believed that the problem should be solved using mental images rather than observations made with the senses. This philosophy had great influence on Greek science. He wrote:

> Astronomy, like geometry, we shall pursue by the help of problems, and leave the starry heavens alone. (3-5)

Plato's view of the universe reflected this philosophy. To Plato, the universe had a mathematical and geometrical existence. He considered all the four elements (air, water, earth, and fire) to be composed of solid figures that were derived from triangles. The particles of fire were tetrahedra, air was octahedra, water was composed of eicosahedra, and the earth was made of cubes. The dodecahedron formed quintessence, the fifth element forming the material of the heavens.

His universe as a whole was a sphere. The four elements were present in the universe in such an amount that the proportion of fire to air was the same as the proportion of air to water, and water to earth. Plato believed that all objects could be designated by a number expressing the proportion of the elements that they contained.

Plato's ideas of creation and life are interesting because he attempts to explain the origin of animals and at the same time ridicule his ideological opponents. He believed that of all animals, man appeared first. Man's head was created first since it was the organ of the soul. The other parts of the body appeared later to prevent the head from rolling about on its own. The body contained a lower soul that governed the animal desires of man. Men who lived badly, according to Plato:

> ...were suitably reborn as women in the second generation....and...beasts who go on all fours came from men who were wholly unconversant with philosophy.

and

> Birds sprang by a change of form from harmless but light-witted men who paid attention to things in the heavens but in their simplicity supposed that the surest evidence in these matters is that of the eye.

and finally,

> The fourth kind of animal whose habitat is water came from the most utterly mindless men. (3-6)

Much of this may have been a tongue-in-cheek essay, but it does indicate Plato's way of thinking. He also postulated the existence of an evil world spirit; a demon who was responsible for the views of the atomists.

Aristotle

Plato's philosophy was very influential, but his successors were forced to depart from his views. Aristotle (C. 384-322 B.C.) displayed a departure from Plato's content and method. His early work on the nature of the universe was speculative, but his later works in biology were based more closely upon observations and contained much new material. His work in the field of astronomy included the notion that the spheres that carried the heavenly bodies around were real physical bodies, not mere geometric constructions. Like Plato, he arranged the heavenly bodies in outward order according to their apparent periods of revolution; namely, earth in the center, then the moon, sun, Venus, Mercury, Mars, Jupiter, and Saturn. But these bodies were on moving concentric spheres rather than on Plato's cirlces.

He supposed that there was an absolute difference in kind between the material of the heavens and terrestial matter. All things below the sphere of the moon were composed of earth, fire, water, and air. The heavens were composed of the fifth element--quintessence. The four elements, according to Aristotle, are properties or qualities rather than substances; one element can be changed into another by overcoming one property by its opposite. For example, if the dry-cold quality of the element earth is changed to wet-cold, then the element earth is changed into the element water. In a similar manner earth, water, air, and fire are interchangeable. This idea laid atomism to rest for about 2,000 years.

Aristotle, like Plato, abandoned the effort to account for physical phenomena by physical forces exclusively. He had some idea of cause and effect relationships, but considered effects to be caused or guided by intellectual design and purposes. For instance, we answer the question, "Why is the sun eclipsed?" by saying that the moon has moved between the sun and the earth, and we cannot see the sunlight. But Aristotle would probably say, "Because it is the sun's nature to be eclipsed." He wrote:

> It is clear that the nature of the thing (event) and the reason of the fact (cause) are identical. (3-7)

Plato and Aristotle's influence had a detrimental rather than a stimulating effect on the advance of science. Aristotle's time marked the end of speculative Greek science and the beginning of empirical or practical Greek science.

Third Period: Hellenistic Period
(Alexandrian Science)

In 338 B.C., Philip of Macedon defeated the Athenians, who lost their early vigor for obtaining knowledge. The Athenians did little more than preserve their achievements; they became superstitious or cynical. They saw little need for speculative science.

Philip's son, Prince Alexander, was tutored by Aristotle who taught him politics, ethics, and science. But this young prince was more interested in continuing the conquests of his father. He became one of the greatest empire builders of history and is known to us as Alexander the Great (356-323 B.C.).

When Alexander conquered Egypt he established the port city of Alexandria and made it into a citadel of Greek science. After its founding in 332 B.C., Alexandria became the center of Greek science. Many Greek scientists moved to Alexandria where the atmosphere for scientific activities was more favorable.

In 331 B.C., Alexander started on his conquest of Mesopotamia and all of central Asia. He took engineers, geographers, and surveyors with him. These men mapped the conquered countries and made observations about each country's natural resources. They collected a vast amount of information anout natural history and geography. The collected information provided the means, and perhaps the stimulus, for the change in Greek science from a speculative to an empirical activity.

Upon the death of Alexander the Great at age 33, his empire fell apart. Egypt was taken over by one of his generals, Ptolemy, who continued Alexander's grandiose scheme. Ptolemy aspired to make Alexandria the world's capital of government, commerce, culture, and intellect. Ptolemy, who also studied under Aristotle, built a "museum" or "Temple of Muses," which was roughly equivalent to a modern university. It was fashioned after the Academy of Plato and the Lyceum of Aristotle, both Athenian centers of learning.

The Museum was staffed by some 100 professors, who were given salaries by the state. Many came from Athens and brought their ideas with them. It was equipped with a library of about 400,000 scrolls (forerunners to books) of literature, mathematics, astronomy, and medicine. It also had a zoo, botanical gardens, astronomical observatory, and animal dissecting rooms. The museum was in existence for 600 years but its first 200 years were the most important to science.

At first, there was a series of successes at Alexandria. They were made possible in part by the official support of the ruling dynasty. But the move of scientists from Athens to Alexandria was also accompanied by a change from a dreamy speculation about the universe to a precise attack on clear-cut problems. Regardless of the cause, Alexandrian science became almost entirely empirical. Their concern with matter was more closely related to that of a craftsman than a theoretical scientist.

The beginning of the empirical nature of Alexandrian science was evident by the rise of a group of well-trained engineers. These engineers worked on many different projects but they concentrated on three main topics--military engineering, the development of more accurate scientific instruments, and the construction of mechanical toys. A water clock, new surveying instruments, a type of catapult, and a type of water pump were some of the items developed during this period of time. Such men as Archimedes (C. 287-212 B.C.), Philo (about 100 B.C.), and Hero (about A.D. 100) took part in these practical scientific activities.

But fortune frowned on the Alexandrians. Their science started to decline. There was a period of stagnation just before the start of the Roman empire. The spirit of scientific progress seemed to have left the activity. Many problems of investigation seemed to reach a natural end. New projects were not found to replace the completed ones. The thrill of accomplishment gave way to caustic comments, criticisms, and reviews of past triumphs. Astrology, imported after the Mesopotamian conquests, was practiced. The present day practice of horoscoping (the prediction of the events of an individual's life from the position of heavenly bodies) was developed during this time.

External influences also became less favorable. As the Ptolemies became more Egyptianized, they favored science less and less. Some went so far as to persecute the Greeks in Alexandria and many scientists moved to more favorable surroundings.

After governing Egypt for about 300 years, the Ptolemy dynasty came to a sudden end with the death of Cleopatra (30 B.C.). At this time the Romans defeated the native Egyptian troops and assumed the administration of Egypt. The Romans were great soldiers, administrators, and lawmakers. They were engineers and mechanics in a practical way. Their world was the world of affairs and not the world of abstract or speculative thought. They were barely sympathetic toward science.

However, the coming of the Romans to Alexandria was not disastrous to science. The Romans showed their usual tolerance to their subjects. They permitted the use of the Greek language and did not change the general atmosphere that prevailed in Alexandria. So life soon returned to normal and the university (Museum) once again became a center of learning and research. But an unfavorable influence to Greek science was just over the horizon.

The Roman conquerors introduced a new technique of government, but the Christian conquerors brought with them a new belief in life and a new concept of human aims and destiny. Their citizenship was in heaven and this life was a preparation for a future life. The world to them was a prison-like house and they took little interest in it. They were not sympathetic to the study of science.

In the next chapter the changes in science that were heralded by the Roman Empire will be discussed. We will look at science from about 100 B.C. to about A.D. 1500.

CHAPTER IV. THE ECLIPSE OF SCIENCE

Greco-Roman Science

The era of Greek influence was followed by a period of about 1500 years during which science floundered or was dormant. Greek science did not decline but it tended to level off during the Greco-Roman Period. The ideas of the Greeks were studied and worked over but there were few new scientific developments after the time of Aristotle.

In the question of the nature of matter, Aristotle had the last important say. His authoritarian viewpoint about the nature of matter influenced thinking on this subject for about 2000 years. His belief that matter is continuous and infinitely divisible overshadowed the theory of atoms for this period of time. The idea of atomism does arise here and there throughout this time but it is quickly obscured by scientific and religious dogma and does not rate important mention in science until about the 1800's. Even then it was not a widely accepted theory of science. The atomic theory was used by a few chemists but not by many other scientists.

A Tale of Three Cultures

In this chapter we will look at three cultures to see how the scientists and his science is used by the people. We will consider the (1) Romans, (2) Muslims, and (3) Christians. Chinese and Indian science were flourishing at this time also, but we will restrict ourselves to the more western civilizations.

Roman Science

The Romans, like the Greeks, came to civilization during the Iron Age. They also became civilized directly from barbarism, but they adopted some of the traditions of the Bronze Age. They joined the civilized world with astrology and liver divination, a practice introduced by their ancestors.

The Romans differed from the Greeks in that they did not develop a civilization of city-states along the sea coast. Rome was a warrior-agricultural community similar to Sparta, the least intellectual of the Greek city-states. The senators of Rome were forbidden to become involved in commerce. The commercial merchants submitted to the trends of their society and aspired to become owners of farm land. They lacked the quantitative and spatial thinking of the Greeks. As Cicero (106 B.C.) said:

> Greek mathematicians lead the field in pure geometry, whilst we limit ourselves to reckoning and measuring. (4-1)

The Romans assimilated a certain amount of Greek science but this assimilation was only fragmentary. They failed to assimilate the theoretical and empirical activities started by the Greeks. The Romans took over the content of Greek science without the method. The writings of the Romans were either primarily philosophical or empirical but they did not combine them. They did not absorb all the content of Greek science. Mathematical sciences had very little appeal to them. As a consequence, Rome had no mathematicians or astronomers of note and only one geographer with any kind of reputation (Pomponius Mela, A.D. 43).

The Romans failed to continue the tradition of Greek science because their interests were different. Their main interests in science were applied science or technology. The scientist did not have much time for independent investigations because he usually was called upon to work on specific problems. The Romans are known for their engineering and practical scientific achievements rather than for theoretical scientific accomplishments.

Roman Achievements

For centuries architects and engineers have been impressed by Roman engineering. Roman engineers devised and built a system of aqueducts that supplied Rome with millions of gallons of water daily. They built roads that connected Rome with all parts of its empire (perhaps you are familiar with the saying, "All roads lead to Rome."). The engineers built a series of military and civilian hospitals where patients were treated at public expense. The surveying of the entire Roman Empire was planned by Julius Caesar and executed by Augustus Caesar. The survey map produced by engineers became the starting point for later trade maps prepared during the Roman Empire.

The nature of Roman scientific activity is illustrated by the development of the Julian Calendar. This calendar reform was initiated under Julius Caesar. The Romans wanted a reliable calendar for administrative purposes, and for agricultural purposes they needed a calendar that corresponded with the seasons and could be used uniformly in all its territories. They utilized Greek astronomical knowledge and replaced all the lunar and other calendars being used in their territories with the so-called Julian calendar. This calendar assumed a solar year of 365 days and a leap year every fourth year (with 366 days). This calendar, which had a discrepancy of three days every 400 years, was used until A.D. 1582. It was adjusted for this error in A.D. 1582 and became known as the Gregorian

Calendar which we use today.

Roman Scientists

.The Romans did not add a great deal to science; their contributions lay in the field of organization. They formed a public medical service and wrote laws to regulate their organizations. As students of Greek science without independent and original development, the Romans were attracted to an encyclopedic kind of science presentation. This is demonstrated in the works of Pliny the Elder (A.D. 23-79). Pliny's Natural History was a compilation in 37 volumes of facts and observations. This was derived from 2000 previous works written by 146 Roman and 326 Greek authors. He wrote about everything he had read--the unicorn and the phoenix bird as well as the lion and the eagle. Pliny stressed the usefulness of the things he described. His general attitude was that nature existed to serve the purposes of man. He also recorded things that he had observed. It has been reported that he was killed while observing an eruption of Vesuvius too closely. However, this is only legend; he did die during an eruption of Vesuvius but was 25 miles from the volcano. It is believe that he died of a heart attack.

Interest in the independent scientific problem, very evident in Greek science, is for the most part lacking in

Roman writings. [illegible] encyclopedia, a comprehensive manual with emphasis o[illegible] [illegible]nition and description rather than on solution and de[illegible]ration, is the characteristic form of Roman science. Thi[illegible] tradition of Roman science was carried on for centuries and was characteristic of scientific writings of European scientists of the early Middle Ages who depended upon Roman science for their heritage.

Roman Influence on Science

The Romans had an unintentional negative influence on Greek science. When the Greeks were conquered by the Romans they became cynical or religious. Both tendencies are evident in their late science but the religious trend was the more dominant.

Astrology

Astronomy was fitted with a theological dress. The early writings of Claudius Ptolemy (A.D. 85-165) show that he was clearly on a par with the best Greek astronomers. In the Almagest, in which he expanded Aristotle's theories of the universe, he displayed his ability to be a critical thinker. Other works of Ptolemy indicate this same critical and rational spirit. However his later work, Tetrabiblos, is a classic example of astrology.

This was the most influential astrological writing of all times. Its influence was felt in the Middle Ages.

The major objective of this astrology (it was built upon earlier Mesopotamian doctrine) is to trace the influence of the positions and the movements of celestial bodies on terrestrial activities in general. The influences that these bodies had on man were the ones of most particular interest. Knowledge of these influences helped predict events, including the character and life of man. This is known as horoscoping which is well known today.

Alchemy

The more important impact of religion upon science was in chemistry with the rise of Alexandrian alchemy. Alchemy, derived from Greek Alexandrian thinking and developed with great secrecy, encompassed cosmology, mysticism, and astrology. It inherited two traditions about the nature of matter: (1) the tradition of the crafts and (2) the tradition of the Greek philosophers. The alchemists attempted to fit together the theoretical ideas of Aristotle with the practical experience of the craftsman. They hoped for a better understanding of matter.

One science historian and student of alchemy singles out three important currents that came together to produce alchemy.

1. The tradition of the practical working metallurgists, especially Egyptian, provided the practical aspect. (At some time during the development of metallurgy, the metals were colored to look like precious metals. The recipes for these technological processes were not alchemical in nature. They do not pretend to accomplish transmutation. The recipes are completely free from philosophical or mystical ideas.)

2. Aristotle's basic view of the elements and their possible transmutation provided the theoretical aspect. (He believed that the elements could be and were continually undergoing transformation, one into another, in nature. The one objective of alchemists was to have the transformation occur at the will of man.)

3. The mystical aspect was derived from several different philosophical views. (The literature of the Stoics and Neo-Platonists provided the mystical elements in early alchemy.)

During the period of early alchemy, Stoicism was the dominant philosophy. The Stoics believed that all of the varied objects of nature were alive and growing. Each individual developed from a seed that contained the form or plan determining the characteristic of the mature objects (they were ardent supporters of horoscoping). Such a form or plan was a soul or spirit and it was brought into activity and sustained by the universal spirit of nature--

the pneuma. Plato believed in the transmigration of souls. In the context of the Stoic philosophy and the religions of the time, this view implied that the form of one object could be transferred to another by a process of death and ressurection.

Following this line of thought, the alchemists believed that metals were living organisms which were developing gradually toward the perfection of gold. They thought that they could speed the process by isolating the form and soul of gold and transfer it to the base metal. Then the base metal would assume the form and characteristics of gold. The soul of a metal was regarded as a spirit or vapor indicated by the color of the metal. Thus, the gilding (surface covering) of a base metal was thought to be a transmutation. The alchemist Zosimus (about A.D. 100) states:

> All sublined vapor is a spirit, and such are the tinctorial (coloring) qualities....The mystery of gold tincture (color) is to change bodies into spirits in order to tint to spirituality. (4-2)

A fairly general process adopted was the alloying of the base metals copper, tin, lead, and iron. This mass of alloy was believed to be primary matter devoid of form. The alloy's surface was then whitened, using arsenic or mercury vapor, to give it the surface quality of silver. Next, a seed of gold was added and the transmutation was completed by another surface process (gilding). The four base metals were presumed dead because of the alloying process. They had lost their soul or form. The assumption of the new forms by surface tinting, first of silver and then of gold, transformed the alloy into gold. The surface tintings were thought to be resurrection processes. This was the beginning of alchemy, which was to endure until about 1800. The alchemists served one very important purpose; they kept the experimentation process alive for many centuries.

Decline of Science

The time of the early alchemists (A.D., 1st to 5th Centuries) is noted for the decline of science, in particular Greek science. Scientific activities became less and less intellectual as the Roman Empire underwent decay and fell apart. A science historian states that the books of the Alexandrian alchemists were burned in A.D. 292 and that the library at Alexandria was destroyed by the Muslims in A.D. 640. This final act against Alexandrian science was ordered by the Muslim ruler Caliph Omar who justified his action by saying:

> ...if these writings of the Greeks agree with the book of God, they are useless, and need not be preserved; if they disagree, they are pernicious (injurious) and ought to be destroyed. (4-3)

After the Christian riots, some of the Alexandrians moved to Athens where science still had a foothold in the Mediterranean region. The Academy of Plato still maintained a feeble existence. However, the natural philosophy was primarily concerned with magic and superstition. In A.D. 529, Emperor Justinian forbade the study of "heathen learning" and as a consequence the Greek schools closed.

The scholars migrated eastward first to Constantinople, then to Mesopotamia, and finally they settled in Persia. Here they were free to occupy themselves with literature and science. They wrote original works in Syriac, their own native language. They translated the works of Aristotle, Plato, Euclid, Archimedes, Ptolemy, and many others into this common West Asian region language.

This was the final stop of the Greek scientific tradition. It started in Ionia (Asia Minor) and Sicily, spreading to Athens and the Grecian mainland. Its influence spread from Egypt to Asia. As the Romans came to power, Grecian science started to migrate again and finally ended in Persia where it was absorbed by the Arabs. We will now consider science in the Arabic empire.

Arabian Science

During many unknown centuries Arabia was inhabited by nomads. These nomads ranged from dreamers to murderous savages. Their religion consisted of many tribal gods and devils. Jewish and Christian ideas had some influence on these wanderers but were of minor importance.

Mohammed was born in about A.D. 570. He was brought up by a rich grandfather, became a child of the desert, and worked on caravans. Later, he became a caravan conductor and married an old but wealthy widow. To his wife, Khadija, and his closest friends he confided that he had received a vision. The vision, according to Mohammed, revealed that there was only one God and that he was his prophet. When this was made public in Mecca he was ridiculed and presecuted by the people. In 622 he fled to Medina where he met with a more sympathetic audience. He founded a brotherhood which eventually grew into a religion of about one hundred million converts. From Medina, Mohammed preached a holy war.

The Arabs started on a career of military conquest. Palestine and Irag fell to them within several years. They invaded Syria (636) and Egypt (639), and had possession of Alexandria in 642. Persia and the western part of Turkestan, a part of western India, northern Africa, Spain, and part of western Europe became absorbed into this rapidly expanding empire. The Arabs built one of the greatest but one of the most unstable empires in history. The empire lasted for about 400 years and during this time it became the curator of scientific knowledge of the world.

Their new way of life gave them visions of bigger and better things than that of the burning desert, so as they conquered they absorbed learning as well as territory. In addition, they acquired knowledge by the immigration of men of science. Greek physicians who treated the Arabian conquerors for a variety of diseases brought much knowledge of Greek science with them.

The scientists employed by the Arabian rulers made a great contribution to science through their translations and summaries of the works of the Greek natural philosophers. They excelled as translators, commentators, and writers of treatises. The aim of their leaders was not to increase knowledge but to accumulate all existing knowledge into their empire. Caliph Haroun-al-Raschid (about A.D. 800) had the works of Aristotle and Hippocrates translated into Arabic. Al-Mamun (about A.D. 830) sent missions to Greece and India to find other scientific works suitable for translation. He also founded an astronomical observatory in Baghdad in A.D. 829.

Al-Kindi (800-873), the first philosopher of the Arabs, issued 265 publications on about every aspect of science. The Persian Rhazes (865-925), who was primarily a physician, not only wrote on measles and smallpox but also on alchemy, theology, philosophy, nematics, and astronomy. There was also Al-Biruni (973-1048) who was a mathematician, astronomer, physicist, geographer, physician, and historian.

Mohammedan science existed in this manner until the 10th Century when conditions began to change. The golden age of Islam was dying as its great empire was breaking up. Its culture was declining and science with it. Science was now considered antagonistic to the Islamic religion and thus came under attack. Eastern Mohammedans became unsympathetic to science and it passed from the scene.

As Arabian science declined in the east, it gained a strong footing in the west. It began in Spain, especially in Cordoba and Toledo. In Cordoba an academy and library were established under the encouragement of Caliphs Abd-ar-Rahman III and al-Hakam II (about A.D. 1000). Gradually, an appreciation for Arabic learning spread over western Europe. Books showing a strong Arabic influence were written on mathematics and astrology. Arabian alchemy, an extension and modification of Alexandrian alchemy, was introduced to the western world by an Englishman, Robert of Chester (1110-1160) in 1144.

A large number of classical books were translated from Arabic to Latin. The works of Aristotle, Euclid, Archimedes, and others became available to Europe in a language they could understand. Probably the most industrious translator was Gerard of Cremona (1114-1187). He learned Arabic at Toledo and translated 92 complete works including writings of Archimedes, Euclid, Ptolemy, and several Arabian scientists. When you consider the unstable conditions at that time, the Arabs did a great service to science by providing a storehouse for scientific knowledge. They guaranteed that knowledge that had been gained was not lost.

Besides these endless translations, Arabic Spain produced some original work in astronomy. But the Arabs introduced one thing to Europe that they had acquired on their conquests in the east. This gift, which Arabian science transmitted to the western world, was the "Arabic" system of numbers (origin in India). This notation was introduced early in the 12th Century by Adelard of Bath 1090-1150). Through the efforts of Leonardo of Pisa (about A.D. 1200) and others, it replaced the commonly used Roman numerals. The Arabic notation gradually became understood and was fairly commonly used by the end of the 13th Century. During this period, the era of tanslation and the recapturing of knowledge from former ages came to an end. Science had been east and had come back to the west. Scientific works had been translated into Latin and now science was ready for advancement by western methods.

Science and Christianity

The interrelation between Christianity and science has varied through the centuries. It has been said that early Christianity was responsible for the leveling off of Greek science. But the Christians and the Romans showed equal indifference to science. The actions of early Christians reflected the attitude that natural phenomena were relatively unimportant and only spiritual values had significance. They believed that the natural world was used by God as a means of communicating specific messages to the faithful. In addition to indifference, the new religion attracted many gifted men to religious study. These scholars turned to the priesthood rather than to scientific endeavors. This trend continued through most of the Dark Ages.

In the 12th Century man's attitude began to change. In the Latin west, people began to pay more attention to the physical world. The renewed interest in nature was promoted by the writings of several monks. In the 13th Century, St. Francis of Assisi expressed the view that nature was worth studying for its own sake and according to him nature had more to reveal than the messages of God. This new notion in Christianity opened the door to natural science.

However, medieval scientists did not contribute much new insight to the study of nature as they were usually members of religious orders that were advocates of the ideas of Aristotle and Plato. Albert Magnus (1206-1280) and St. Thomas Acquinas (1225-1274) were mainly responsible for this point of view. They integrated Greek philosophy with Catholic theology. For example, they argued that man derived knowledge from faith and natural reason. Since knowledge due to faith and natural reason is derived from God they must be in agreement. And since the writings of Aristotle and Plato provide supreme examples of natural reasoning, they must be in agreement with Christian doctrine. This argument was so convincing that the Catholic Church considered an attack on Aristotle's ideas an attack on the church.

A Franciscan monk, Roger Bacon (1214-1294), added to the views of St. Francis by saying that there are two sources of knowledge, the Book of Scriptures and the Book of Nature, and that everyone should learn from both books. He was critical of scholars who based their opinions upon authorities or customs and hid their ignorance by wordy arguments. The true student he said, should know:

> ...natural science by experiment, and medicaments, and alchemy and all things in the heavens or beneath them....(4-4)

He felt that man would be able to construct self-propelled boats and land carriages through the study of science.

Bacon's point of view was not popular and he frequently met with obstruction from his religious superiors. He was reprimanded, and spent much of his life in virtual imprisonment.

Bacon's idea, natural theology, changed the role of men from passive recipients of spiritual messages through natural phenomena to active seekers of an understanding of the Divine nature. Natural theology was the motivational basis for late medieval and early modern science. Almost every scientist from 1250 to about 1650 considered himself primarily a theologian. Leibnitz and Newton are notable examples. They practiced science and mathematics with the patience and devotion of a monk.

Natural theology was a major foundation of western science. But why did the idea of an experimental natural theology emerge? One science historian feels that it may have sprung from the key religious struggle of the time. This was the spiritual battle between Latin Christianity and the Cathar heresy. Early in the 13th Century it looked as though the Cathars were going to split the Holy Roman Empire in half by acquiring control of a strip of territory extending from the Balkans across Europe almost to the Atlantic coast. This acquisition would have separated the Papacy from the orthodox areas of northern Europe. The Cathar's major doctrine was that there are two gods--

a god of good and a god of evil. They claimed that a god of evil created the visible universe and that living a good life involved having as little contact with the physical world as possible. Christianity held that matter is the creation of one good God and used the doctrines of natural theology to defend its position. In the process of defending the Christian position against Catharism--by emphasizing man's interaction with his physical world--natural theology became more relevant and more clearly understood. (4-5)

The death of Bacon marked the end of an era. A new era was beginning. Men would no longer try to discover the truth by reading the opinions of ancient writers, but would examine the works of nature firsthand. Latin science was profiting by its access to Greek scientific writings, but the trend of thought was away from Greek scientific methods. The human mind was regaining its long-lost freedom of thought. It had the writings of the Greek age of science. But science needed one more thing before it could expand; the invention for this need came at just the right time.

Printing

The Europeans had known the art of paper-making for several centuries. They also knew how to use block printing but they needed something more. This something extra was invented in Europe in the 15th Century. Printing using movable type--invented by Coster and Gutenberg in 1450--had a tremendous influence on the development of science. It improved printing and the dissemination of scientific information. Since this time, printed books have become available in ever-increasing quantities.

Printing did not make scientific knowledge more available immediately because religious and literary works were printed first. The Bible (1456) and other classical works were given priority. Pliny's Natural History appeared in Venice in 1469.

In the beginning, the printers printed inferior works of science, but after 475 many Latin translations of Greek scientific works were selected for printing. For example, Ptolemy's Geographia (1475), three biological works of Aristotle (1476), Euclid's Elements (1482), and a Greek edition of Aristotle's work (1495) were printed before the start of the 16th Century.

With the advent of type printing, everyting seemed favorable for a period of vigorous scientific activity. It came rather slowly in the 16th Century, but during the 17th Century the dam broke. We will consider some aspects of science during these two centuries in the next chapter.

CHAPTER V. REBIRTH OF SCIENCE

Introduction

At the present time, a great majority of people believe that science is the most reliable source of information. They feel that science is exact, impersonal, and not influenced by bias or prejudice. They think of science as progressing from achievement to achievement, using relevant data, and resulting in power to control nature. Many people are so accustomed to this idea that they take science for granted. This idea of science, called "scientism," represents a fairly modern view of science. During the Middle Ages an almost opposite view of science was popular.

During the Middle Ages (A.D. 600-1400) there were new discoveries but most of the men of science were occupied with the recovery and preservation of ancient knowledge. The spirit of science was of subordinate importance to the general scheme of thought. New ideas were distrusted. Many scientists mixed experiments with mysticism and tried to control nature by magic. The main outline of truth that was laid down by theology and philosophy was fixed and unchanging. Aristotle's ideas, such as the "primary elements," were accepted and protected by religious powers during the Middle Ages. This idea, in addition to many others, was accepted as adequate explanation of the nature of existing things.

The standard for methodical thought was set by the great theologians, philosophers, and jurists. This standard gradually changed because somewhere between the late 15th and late 17th Century a new scientific spirit took hold of many scientifically oriented minds. At that time, a transformation occurred in western and central Europe but no where else.

Universities

This transformation could be traced to many sources but we will consider only two. One science historian gives much credit for the rebirth (renaissance) of science to the university tradition. He states:

> ...the Renaissance had an intellectual aspect. The artists investigated optics and anatomy; the closer and deeper study of ancient Greek writers not only equipped Europe with better textbooks of mathematics, physics, medicine, and zoology, but it sharpened method in every kind of research....widening experience of men of action brought masses of new knowledge about the world, and also set new problems which the men of action could not solve for themselves. The new facts would not have been assimilated and the new problems would not have been tackled if there

> had not already been in existence a magnificent organization of thought and education. It was the traditional work of the universities to keep themselves at the height of the best knowledge of the time. There was constant emulation between them and it was in the universities that the first striking advances of modern science were made.

and

> ...the original point d'appui from which modern science was able to set out to make converts in every other sphere of life was the medieval university. (5-1)

The universities had arisen from guild-like associations of masters and students. The occasion for the rise of the universities was a great revival of learning during the 12th Century. The words "guild" and "university" were originally used to describe craft organizations but by 1300, the term "university" was used as a term to mean student organization.

There were basically three types of universities. The first was the church founded schools, in which students and masters formed a corporation. Paris, Oxford, and Cambridge are examples of corporations run by an appointed chancellor. The civic universities such as Bologna and Padua were independently formed and were governed by a rector who was elected by the students. The third group of universities was founded by ruling monarchs and authorized by the Pope. Many state universities such as Naples (founded by Frederick II of Sicily) were organized throughout western Europe. By the end of the Middle Ages, at least 80 universities had been founded in different parts of Europe.

It has been the tradition of the university to keep abreast of the newest knowledge. Like Plato's Academy and Aristotle's Lyceum, the universities have usually strived for the acquisition of knowledge. There has been constant competition between the various schools. The universities have not only recruited men but they have also equipped them with mental tools. Many of the essential ideas of modern science were quietly prepared during the Middle Ages by these university-trained thinkers.

Scientific Societies

However, many of these schools became dominated by conservatives and authoritarians so that the university declined for a period of time as a center of modern scientific thought. It gave science a new start, but its influence during the Middle Ages was short-lived. When the 16th Century brought the general revolt against authority the need was felt for some sort of meeting place, where science could exist in a sympathetic atmosphere. This need was met by the formation of scientific societies or academies.

Italian Scientific Societies

Italy was the first to translate this need in active reality. In 1560 the Accademia Secretorium Naturae was founded in Naples but it was closed soon after its founding for meddling with witchcraft. A similar society, the Accademia dei Lincei, existed in Rome from 1603 to 1630. It was founded under the patronage of Duke Federigo Cesi. The 32 member society split over the Copernican theory in 1615 and dissolved when their patron, Cesi, died in 1630. Grand Duke Ferdinand di Medici and his brother, Leopold, were patrons for the third Italian society, the Accademia del Cimento. It was founded in 1657. In 1667, Leopold Medici was made a cardinal and the academy was dissolved.

England's Royal Society

Francis Bacon (1561-1626), who wrote extensively about the methods of science, advocated the formation of a national scientific society but no society was founded in his lifetime. In 1662, Charles II founded the "Royal Society for the Improvement of Natural knowledge" and thus placed a stamp (actually a seal) of approval on an organization already in existence. He provided an official meeting place for English men of science. Actually, many of these men had been meeting unofficially and informally since 1645. They first met at Gresham College in London under the name of "Invisible College." During the civil strife between Royalists and Parliamentarians (1640's and 1650's), the members of the "Invisible College" met at Oxford and later they met again in London.

The main body of the Royal Society consisted of men trained at the universities. Many made their careers in university work but the Royal Society had nothing to do with teaching. The scientists in this society were associated with men of political position and power. These men (some were amateur scientists) kept the scientists in touch with the needs of government, agriculture, transportation, and industry. The scientists sought ways to meet these needs and in return for their services, benefactors provided prizes for inventions, special honors, and rewards for intellectual excellence. They also paid for a few posts for research workers, but that was the extent of their patronage.

French Scientific Academies

In France, the development of scientific institutions followed a course similar to that pursued in England but there was one important difference: French science was much more dependent upon patronage than English science during the 17th Century. The earliest scientific group in France met in Aix on an informal basis in 1620. In 1654, it became a formalized group and met at the house of Habert de Montmor (1600-1679), a Counsellor of State.

The Montmor Academy ran into financial difficulties and closed. So in 1663, Colbert (1619-1683), Louis XIV's minister, argued that the advance of science would benefit France economically. He felt that the application of science would further his policy of expanding the industry and commerce of France. He founded a new scientific society under the patronage of the French crown. Thus, in 1666 the Paris Academy of Sciences was founded. It consisted of about 20 members at the start, each member receiving a salary paid by the King.

The academicians were professional scientists working as a group upon problems set to them by the royal ministers. The Royal Society, in contrast, was self-supporting and many of the members were amateurs who worked on their own research.

The academy gradually increased in membership. In 1699, it consisted of 70 members whose positions were arranged in a hierarchical order. Some members had different privileges and rights but the academy as a whole was still controlled by the royal ministers. During the French Revolution, the Paris Academy was reorganized and granted a constitution in which all members had equal rights. This academy was called upon by the new French government to devise a system of measurements. It is this group that was responsible for the development and adoption of the metric system of measurement.

German Scientific Societies

The German scientific societies of the time were not very important. It was not until the 18th Century that a stable scientific academy was set up in Germany.

These German scientific societies were not an immediate success because the roots of science were not well established. It is interesting to note that Germany later became a nation of great scientific activity. France recognized the importance of a national science before any other nation, but Germany was the first country to use science for the development of political power. She did this during the late 19th and early 20th Century by institutionalizing science at the national level. We will look at this in the next chapter.

Most of the scientific societies published scientific periodicals which carried reports on the latest experiments, calculations, tables, and diagrams. They replaced the book as the basic means of transmitting current scientific information. The findings of the scientists from the time of the early scientific societies to the present have been made available to an international public through the introduction of scientific periodicals.

Motives for Scientific Advancement

The scientific society movement, together with the work of independent scientists scattered throughout Europe, brought about a great advance in practically every branch of science. Astronomy had the greatest triumph with the work of men like Galileo, Kepler, and Newton. Chemistry and its related sciences were set on sound foundations. Anatomy and physiology entered a new era. But all of this did not come about by accident. As one science historian states about the scientific revolution of the 17th Century:

> It would be very undiscerning to suppose that such a period of greatness could arrive as a mere accident, an especially brilliant galaxy of exceptional minds just happening to be born at one particular epoch. Mental ability is believed to be transmitted in accordance with the laws of heredity, in which case the laws of probability will see to it that no abrupt jump occurs from one generation to the next. Thus a period of greatness must be attributed to environment rather than to accident; if an age shows one particular form of greatness, external conditions must have encouraged that form. (5-2)

What were the external conditions? One science historian merely classifies them as motives. All the motivations cannot be singled out because there are a large number of motives. Some seem to be more important than the others. Let's look at these.

Economic Motives

There were economic motives. The Portuguese, Spanish, Dutch, and later, the English wanted better means of navigation for their trade routes. They needed to develop methods of navigating water without being in the sight of land. This required the determination of a ship's position in the open sea. As a consequence, various countries promoted the study of this navigational problem.

They established observatories for the study of astronomy and offered cash rewards for solving this navigational problem. The problem stimulated much activity in the study of astronomy and mathematics throughout western Europe. Renowned scientists, even Gailileo, attempted to solve it. The problem was not solved until 1760 but it stimulated the study of Greek works on astronomy and eventually resulted in new achievements such as Newton's principle of gravitation.

Germany was not concerned with navigational problems. She was faced with problems in mining. The German mine owners were concerned about the pumping of mines. They also had many questions about metallurgy. The Italians were involved with the building of cities, improving their canals, locks, and harbors. These countries promoted the study of liquids and solids.

It is interesting to note that the countries with strong commercial and industrial interests were the most encouraging to science. The Portuguese and Spanish encouragement was not very pronounced but the nations of Italy, Germany, and the Netherlands were great promoters of science. During the late 16th and early 17th Century, the men of these countries contributed the most to the advancement of science. Later, England and France began their development of applied and pure science. They profited greatly from their commercial ventures and geographic discoveries due to science, and by the middle of the 17th Century, they had well-established scientific traditions.

Practical Motives

More practical motives also influenced the increased interest in science. Physicians and surgeons were looking for new operations and new medicines so that they could do more good than harm. These studies began with the earlier work of Andrea Vesalius (1514-1564) and were continued with the work of William Harvey (1578-1657), Marcello Malpighi (1628-1694), and Anthony van Leeuwenhoek (1632-1723)--one of the developers of the microscope. The work of these men and others revolutionized the study of anatomy and physiology. Their discoveries paved the way for further study of the circulation of the blood and its function.

Another practical motive was the development of better military weapons. Soldiers, like the physicians, requested aid from the scientist. They wanted assistance in the designing of artillery cannons. The military also wanted to devise methods of aiming these weapons. At the same time, the military asked the scientists to aid in the planning of fortifications. These problems required the study of mathematics, mechanics, and other areas of science. The scientists again went to the classics for answers. In the process, some came away dissatisfied with the Greek explanations and eventually developed their own.

Many other practical problems were tackled and investigations were conducted by artists as well as craftsmen. Jewelers wanted to learn more about precious and semiprecious stones, musicians became interested in the mathematics of harmony, and painters and architects studied light and color.

Religious Motives

From the time of Anaxagoras (about 500 B.C.), religion had been unsympathetic and often hostile to science. In the Middle Ages, it had often been the main hindrance to to science. It is hard to imagine today how religion dominated thought during this time. The Renaissance came and gave man a wider vision, making him aware of an external world that was worthy of study. Intense preoccupation with religion diminished as the church withdrew its long opposition to the study of science.

The Catholic Church promoted the science of astronomy. It wanted to reach an absolute correctness in calculating the dates for the annual fixed, and movable festivals of the church. Pope Gregory XII presided over the astronomical investigation which resulted in the modification of the Julian Calendar.

Finally, there is a more subtle religious motivation. As one historian states:

> For a number of reasons religion impelled men to scientific study....Deeper and stronger (than the other reasons)was the desire to study the wonders of science, and the order which it unravelled in the universe, as manifestations of the Creator's will. This was closer than any of the other motives to the central impulse which actuated them all, the disinterested desire to know. (5-3)

Regardless of the motives, by the close of the 17th Century, natural science had made advances in achievement, practical applications, organization, and public reputation. Science now had the means of propagation. Several universities were established as institutions which housed some of the great experimenters and thinkers. Some scientific societies were already established. With the help of improved printing, transportation, and postal service, science and Europe grew together in prosperity.

The Century of Genius

Before leaving the 16th and 17th Century, it seems appropriate to look at some of the men who contributed to the new directions of science. The 17th Century is often referred to as the "Century of Genius," because many of its men contributed much to the advancement of science. Although they are looked upon with favor today, they were often misunderstood and persecuted during their lifetimes. We will consider four of these men. This will give you an example of early modern science and an idea of the scientific contributions of these men.

Francis Bacon (1561-1626)

Francis Bacon was born shortly after Queen Elizabeth came to the throne. His family belonged to the higher ranks of civil service. He was a very bright boy and the Queen enjoyed talking with him. He went to Trinity College, Cambridge at the age of 13 and left two years later. Bacon made law his profession and was employed by the Queen but held no important offices during her reign (she did not trust him). After James I ascended to the throne (1603), Bacon moved rapidly up the official ladder. He became Lord Keeper, Lord Chancellor, and in 1620 Viscount St. Albans. A year later he was charged with corruption, pleaded guilty, paid a fine of 40,000 pounds (about $100,000 today), lost his office, and was banished from the royal court. Bacon died five years later, a broken man.

Bacon was not a scientist; he did not do any experimental work in science. He probably was ignorant of the great work of scientists of his time. If he did have knowledge of them it is not evident from his writings for he never mentions men like Kepler, Vesalius, or Gilbert who was his physician. But his writings were to have great influence on science.

Bacon was convinced that man's ignorance of nature was not inevitable. In his opinion, man's lack of power over nature was the fault of man. Bacon felt that we could understand nature better if we used a different method. In his book Novum Organum (1620)--The New Instrument--he stated what was wrong with the methods of science. What was wrong with the method during Bacon's time? Two things:

First, there was a complete divorce between theory, observation, and experiment. Most experiments were performed without any theoretical basis. The combining of experimentation with practical applications was very poor. Men performed their work for immediate and practical aims and kept their results a secret. Men did not seek any relationship with matter; they merely worked with matter by using empirical methods.

Secondly, on the theoretical side, scientists accepted Aristotelian thought uncritically. They decided all questions by appealing to the "infallible authority" of Aristotle rather than by observing observable facts. Aristotle had reached his general principles by hasty and uncritical generalizations from a few superficial observations. He used these generalizations as starting points for his deductive logic. Aristotle used deduction to reach conclusions about nature from self-evident truths. His work was the model for almost all scientists at the time of Bacon.

Bacon had the insight to see that Aristotle's deductive approach--useful in courts and politics--was inadequate for science. He wanted a method by which observed facts gave rise to wider generalizations. In this method generalizations were to be tested at each stage of development by deliberately looking for exceptions to it. If exceptions were found, the generalizations were to be rejected or modified. The method of going from facts to generalizations--known as induction--was being used unconscioully by many scientists, but Bacon identified the general principles of inductive reasoning. As one science historian points out, Bacon's plan was:

> 1) to collect "reliable tested information," especially by means of experimentation.
> 2) to classify this material by "tables of invention," so that all the instances of the phenomenon could be compared.
> 3) By these tables he would arrive at minor generalizations, which we would call theorems or rules, and, by comparing these, he would rise to general Scientific Laws.
> 4) These laws, when found, must confirm themselves by pointing out new instances of the phenomenon studied. (5-4)

What was Bacon advocating? The integration of the methods of the scholarly and craft traditions. He wanted to bring about:

> The true and lawful marriage of the empirical and rational faculties, the unkind and ill-starred separation of which has thrown into confusion all the affairs of the human family. (5-5)

Bacon's views had insight but he had one blind spot: mathematics. His view was essentially experimental, qualitative, and inductive. He distrusted mathematics and the art of mathematical deduction. He was aware that mathematics was a useful tool, but he felt that it--like logic--was dominating and stifling scientific activity. The absence of mathematics was perhaps the main defect, but Bacon's idea had great influence on later scientific activity. According to most stories, Bacon was an advocate of experimentation to his death. They say that Bacon died of exposure to cold air while stuffing chickens with snow--he was testing the preservative qualities of ice.

Rene' Descartes (1569-1650)

Descartes was born near Tours and was educated at a Jesuit school, where he showed great aptitude for mathematics. He studied with Mersenne, a famous Parisian mathematician, and then served a brief period in the army of Prince Maurice of Orange. At the age of 25, Descartes resigned his military commission to devote the rest of his life to mathematics and philosophy.

On the European continent, Descartes was preoccupied with the same problem as Bacon. Bacon was a lawyer who believed in the need for evidence but Descartes was a mathematician and philosopher--as well as being a scientist--and believed in reasoning. His Discourse on Method was also a new way of finding the principles of nature. Descartes believed that with a minimum of observations, scientists could arrive at the principles of nature. He also believed that through a long chain of reasoning man would understand the whole course of nature.

His doctrine was to accept nothing until you see it's truth "clearly and distinctly." He said you must divide difficult problems into smaller and smaller parts until you come to some proposition so simple that you see its self-evident truth. What was his self-evident starting point? Your own existence. Descartes believed that you can doubt anything except your own existence. You cannot doubt your own existence because you must exist to doubt; you cannot doubt about doubting.

While Bacon advocated experimentation and induction, Descartes preferred mathematical reasoning and deduction. In other words, they held opposite views. Bacon gave little or no attention to mathematical reasoning and Descartes made precisely the opposite error in avoiding experimentation. Science is fortunate that Bacon and Descartes were able to conceive of these methods, but it is even more fortunate that later scientists such as Newton were able to integrate Bacon's and Descartes' methods.

Isaac Newton (1642-1727)

Newton, one of the greatest figures in the entire history of science, was born Christmas day, 1642. His father was a farmer who died a few months before Isaac was born. After his mother remarried, Isaac lived with his grandmother. He attended grammar school at Grantham, Lincolnshire, where, after a dismal start, he became an outstanding student. When his mother's second husband died he returned home but he was not a good farmer so he was sent back to preparatory school.

In 1661, Newton entered Trinity College, Cambridge. His tutor was the celebrated mathematician, Dr. Isaac Barrow, who gave much attention to the shy but active and mechanically-minded Newton. With guidance from this able teacher and close friend, Isaac Newton showed his genius for mathematics.

In the autumn of 1665 the spread of the Great Plague caused the closing of the university until the spring of 1667. During these 18 months, Newton laid the foundations for all his famous discoveries in mathematics and physical science. While working in a wood shed on his mother's farm, he discovered the fundamentals of (1) differential calculus and (2) expansions into infinite series (this includes the binomial theorem).

These advancements in mathematics alone would have entitled him to one of the highest places in the history of science but he contributed two other works of unusual significance. One was the discovery and naming of the spectrum. Newton, with the aid of a glass prism, succeeded in separating sunlight (white light) into the colors of the rainbow.

The fall of an apple, according to Voltaire's story, led Newton to ponder on the nature of gravity. He proposed (to himself) that what affected the apple might also effect the moon. If the moon were held to an orbit by gravity, then, he surmised, the same would be true of the planets as they orbit the sun. He enlisted Kepler's laws of planetary motion to explain the pull of the sun upon the earth. Supposing the force of attraction to vary inversely as the square of the distance, Newton calculated the attraction between the earth and the moon. He did not work on this matter again until 1685. Newton finally published this work in 1687 and changed the face of science.

In 1669, Newton succeeded Isaac Barrow as Lucasian professor of mathematics at Cambridge. Barrow, who was aware of Newton's unpublished achievements, resigned the Lucasian professorship so that Newton could replace him. By the age of 24, Newton had made some fundamental discoveries, and at the age of 26 was professor of mathematics at Cambridge. He summed up his 18 months of discoveries as follows:

> I was in the prime of my age for invention, and minded mathematics and philosophy (i.e., science) more than at any time since. (5-5)

From 1687 on, Newton took a more active part in public life. He served as a member of Parliament (1689), became warden (1695), and four years later, master of the mint. He was elected president of the Royal Society in 1703 and was annually reelected president for 25 years until his death. Newton remains an inspiring legacy to all who participate in science. He was buried in Westminster Abbey and his statue stands in the Chapel of Trinity College.

Before we leave Newton, let's look at another of his contributions. We have discussed the methods of Bacon and Descartes, but it was Newton who had the insight to integrate Bacon's experimental induction with Descartes' mathematical deduction. Newton took the universe and subdivided it into small corpuscles and then rebuilt it using his corpuscles and the principle of gravitation. He arrived at the inverse square relationship for gravitational force by deduction and then verified it by performing numerous calculations. Newton set the style for generations of succeeding scientists by taking the observation and experimentation of Bacon and combining it with the mathematical reasoning of Descartes. Newton's scientific style is looked upon as the approach that changed ancient empirical science into modern experimental science.

Galileo Galilei (1564-1642)

This Italian astronomer and physicist was born in Pisa in 1564. His father, who was a merchant and musician, taught Galileo music. Galileo could play the lute and the organ well. In addition, he won a reputation for his excellent paintings. But his father encouraged him to become a doctor. So Galileo studied medicine and the philosophy of Aristotle at the University of Pisa.

At the age of 20, he made his first scientific contribution. As a student at Pisa, he discovered the law of the pendulum. While sitting in the cathedral he observed the swing of a lamp suspended from the ceiling. Galileo timed the motion of the lamp with his pulse beat and noticed that each swing took the same amount of time. He suggested that a simple pendulum be used to time the pulse beat of patients. Galileo also made diagrams for a mechanical clock which were later used to build clocks and chronometers.

Galileo left the university in 1585 because he lacked funds and abandoned medicine for research in mathematics. He returned to Pisa, at the age of 25, as professor of mathematics. While teaching at Pisa, his experimentation led him to the conclusions that all bodies fall to the earth with the same acceleration, regardless of weight. Galileo made public his findings which contradicted the ideas of Aristotle. Supporters of Aristotle, who said heavy objects fall faster than lighter ones, opposed Galileo's theory and forced him to leave the university.

In 1592, Galileo became a professor at the University of Padua. By this time his reputation as an experimenter became known throughout Europe. He started to investigate the principles of the telescope, also building and selling them. He made larger and more powerful telescopes than had ever been made before and sold them throughout Europe. His historic achievements in astronomy and his personal problems were yet to come.

His telescopic studies of the moon revealed that Aristotle's explanation was wrong again. The moon was not a smooth sphere shining by its own light. Instead, its surface was pock-marked with valleys and mountains and the moon showed only reflected light.

Galileo studied the Milky Way and discovered the four bright satellites of Jupiter and the peculiar shape of Saturn. His studies of the heavenly bodies increased his conviction that the sun was the center of the solar system as stated by Copernicus (heliocentric theory). He began opposing the old description of the univers because the earth appeared to move. It was not stationary as stated in the Aristotle-Ptolemy theory of the universe. When Galileo stated this conviction, he was opposed by churchmen and supporters of Aristotle's theories. Galileo got into serious trouble with this group.

But Cosimo II, a member of the influencial Medici family and the grand duke of Tuscany, became Galileo's patron and protector. Cosimos made Galileo his personal mathematician at Florence and at the University of Pisa. Galileo made other discoveries and enjoyed a period of tranquility. On a visit to Rome, he used his own telescope to show Pope Paul V and other high church officials his astronomical discoveries. In spite of the demonstrations the Copernicus-Ptolemy dispute persisted. The church opposed Galileo's report on sunspots and he was advised against speaking publicly about the Copernican theory. But this did not deter Galileo.

In 1632, Galileo published his masterpiece, A Dialogue on the Two Principal Systems of the World. This work, as well as a later one, was written in the form of a dialogue. It was a dialogue between two of his friends and supporters, Sagredo and Salvati, and an advocate of the Aristotelian point of view, Simplicus. The dialogue, which clearly showed Galileo's bias, was written for the comman man to understand. Galileo hoped to give his works a wide appeal and to discredit Aristotelian cosmology. Simplicus, who supported Aristotle's views, bore a very strong resemblance to the Pope. Enemies of Galileo convinced Pope Paul that he could not longer ignore him and his activities so the

Pope ordered an Inquisition.

An Inquisition called Gaileo to appear before it, and after a long trial, Galileo was forced to say that he had renounced his belief (recant) in the Copernican system. A story of his trial relates that he publicly announced that the earth did not move, but he mumbled to himself, "but it does move." The officials of the Inquisition sentenced him to an indefinite prison term for his previous activities, but instead of imprisonment, he was confined to his villa in Florence.

He spent the remaining years writing his second dialogue: Dialogues on the Two New Sciences (1638). This publication was smuggled out of Italy and published in Holland. It summarized all of Galileo's work on motion, acceleration, and gravity. He furnished the basis for Sir Isaac Newton's later success. Galileo went blind before he published this dialogue but the Inquisition constantly watched him until his death. He died five years later in 1642. He was buried in Florence in the church of Santa Croce. Fifty years later, the city of Florence erected a monument to honor the man who unknowingly established a new general method of scientific thought--a method of empirical observation and mathematical deduction.

Galileo realized that his work was not an end, but a mere beginning. He could see its potential for the future.

His belief was in the future of science. In his *Conversations and Mathematical Demonstrations on Twŏ Branches of Science* he wrote:

> ...I have discovered by experiment some properties of it (motion) which are worth knowing and which have not hitherto been either observed or demonstrated...and what I consider more important, there have been opened up to this vast and most excellent science, of which my work is only the beginning, ways and means by which other minds more acute than mine will explore its remote corners. (5-7)

Some of the progress that Galileo predicted will be discussed in the next chapter.

CHAPTER VI. 18TH, 19TH, AND 20TH CENTURY SCIENCE

18th Century

1700-1750

The scientists of the 17th Century had been versatile. They were amateurs who were interested in applied and pure science and they had considerable success in both fields. They developed the pendulum clock, thermometer, barometer, telescope, microscope, air pump, and other applied science products. But they had not made much progress in the development of the marine chronometer and the steam engine.

In the early 18th Century, craftsmen finished what the gentlemen-amateur scientists had started. The marine chronometer, used for finding longitude at sea, was finally developed in the 1760's by an English watchmaker, John Harrison (1693-1776), and a French clockmaker, Pierre Le Roy (1717-1785). The first successful steam engine for pumping water from coal mines was developed by Thomas Newcomen, an English blacksmith.

The first half of the 18th Century was another twilight period in the history of scientific thought as it could not compare with the period before (the 17th Century) or the period after (the 19th and 20th Centuries). As one science historian states about the early half of the 18th Century:

> Scientific activity seems to have slackened in the period between the commercial expansion of the sixteenth and seventeenth centuries and the agrarian and industrial revolutions of the eighteenth....the merchants and overseas trading companies in England did much to promote science in the earlier period, while the industrial revolution was not without its influence upon science in subsequent times. In between there was a period of readjustment and reorientation in which science subsisted largely upon its own established tradition without much stimulus from external agencies. (6-1)

In England, toward the middle of the 18th Century, the influence on science came from new external agencies. The decline in geographical expansion was followed by agricultural reform and the industrial revolution. Gentlemen landlords introduced crop rotations and improved livestrock breeds while in the towns, men with less than wealthy means were starting the industrial revolution. The wealthy amateur scientists was slowly disappearing. The French were considering many of the ventures being carried out in England but they did not implement them. The French government exercised rigid controls on all scientific activities.

1750-1800

The decrease in scientific activity during the early

18th Century was followed by renewed activity. But science had changed. A science historian's impression of the time is as follows:

> With the new movements of the second half of the eighteenth century science revived again, though now it had new characteristics. One of the most pronounced was the methodological division of science along national lines. Most of the natural philosophers of the seventeenth century had been concerned with the experimental, theoretical, and the applied aspects of science....But during the eighteenth century English scientists were mainly experimentalists, and the French were primarily theoreticians, while applied science passed over from the gentlemen-amateur scientists to the instrument-makers and engineers of England and, to a lesser degree, of France. The English Astronomers Royal, Bradley (1692-1762), and Maskelyne (1732-1811), made notable empirical observations and discoveries, while the French scientists, Lagrange (1736-1813), and Laplace (1749-1827), developed the theory of mechanics and astronomy. In the same way Lavoisier (1743-1827), worked out the theory of the chemical revolution, using the experimental discoveries of the English scientists, notably Joseph Priestley (1733-1804). (6-2)

Division Along National Lines

The division along national lines was propheted by the works of Bacon and Descartes who had advocated empirical and deductive aspects of scientific activity. Their 17th Century writings promoted the great 18th Century division. But more important were the national preoccupations of

England and France.

England

England was occupied with the industrial revolution. By developing experimental and applied science, the English scientists and engineers became a great driving force in the expansion of industry. Their investigations were very important to the improvement of industrial technique and equipment. The heat experiments of Joseph Black (1728-1799) are an example. The findings of this experimentation were put to immediate and practical application in the new steam engine developed by James Watts (1736-1819).

France

France was preoccupied with the events leading to the French Revolution. French scholars concentrated on criticizing the doctrines of the established church and state. Thus a theoretical and rather impractical spirit influenced French science. The criticism of church and state was conducted in the name of science. France produced little technical equipment during this time, her only contributions to the early part of the industrial revolution being equipment for certain luxury trades, such as the Jacquard loom for weaving patterned cloth.

Social Background of Scientists

There was also a great difference between French and English science in terms of social background. The English scientists were no longer connected with the trading companies or wealthy land owners. They were mostly sons of poor men, craftsmen, or products of the craft traditions. Joseph Priestley, whose experimentation helped Lavoisier develop a new chemical theory, was the son of a weaver. John Dalton (1766-1844), the formulator of atomic theory, Humphrey Davy (1778-1829), and Michael Faraday (1791-1867) were at one time craft apprentices. These men were more concerned with chemistry and electricity than with other aspects of science such as astronomy and mechanics.

French scientists continued to come primarily from families connected with the state bureaucracy. Men from lawyer families or with training in law, such as Voltaire, still had an important place in the scientific movement. Lavoisier, considered the father of chemistry, was a typical 18th Century French scientist. He earned a degree in law and was also well-versed in several sciences. He became a member of Ferme Generale, a private French tax-collecting organization. Later, Lavoisier was appointed director of the state gunpowder industry. He made great contributions to science, particularly chemistry, but his association with a tax-collecting firm led to his downfall.

When the revolution came, the members of <u>Ferme Generale</u> who had made themselves rich at public expense, were arrested, tried, and condemned to the guillotine. Attempts to save Lavoisier's life were unsuccessful. His association with the <u>ferme</u> outweighed his contributions to science (in the opinion of the French revolutionists). So, at the age of 51, the greatest chemist of that time died. During his final decision, the French judge remarked that:

> ...the Republic had no need of savants (scholars).

Centers of Scientific Activity

This disucssion has been concerned with England and France because they were the major centers of scientific activity. However, citizens of other countries were experiencing scientific activity, but not of the magnitude of the English and French. The spread of science to other countries was influenced by the industrial revolution and protest against religious authority. Switzerland became an important center of scientific activity at this time, probably because many Protestant scientists left Catholic lands. The Bernoullis, a family of mathematicians, left Flanders and settled at Basle. French Huguenot families left France and settled at Geneva. On the other hand, Sweden, with iron-rich ore and great timber forests, became an important center of iron production and scientific activity. Her scientists, like those of England, came from fairly humble backgrounds. Carl Linnaeus (1707-1778), a great pioneer in biology, and Jakob Berzelius (1779-1848), a leader in 18th Century chemistry, were the sons of church pastors. Carl Sheele (1742-1786), another outstanding chemist of his day, was an apothecary's (pharmacist) son.

The scientific centers of France and England also changed. The main French societies concerned with science were those of the south--Montpellier (founded 1706), Bordeaux (1716), and Toulouse (1746). They were members of the Paris Academy of Sciences. The provincial societies carried out much valuable work during the 18th Century but all of this changed with the French Revolution. We will consider these changes later in this chapter.

England's scientific center, The Royal Society (the main center of Newton's activities), became less and less important. Provincial centers appeared in the industrial midlands and the north. These centers were the result of Nonconformism and industrialization. Various Protestant sects refused to conform to all the demands of the 1662 Act of Uniformity. These nonconformist activities were political at the start but it was reoriented to support the crafts. The movement took a leading part in the industrial revolution. A science historian lists three main contributions made by this movement: they established a new educational system, developed certain industries, and decentralized English science.

In regard to education he writes:

> As the universities (Oxford, etc) were closed to them, the Nonconformists set up their own educational establishments, some of which reached a university standard of teaching during the eighteenth century. Many Anglicans chose to go to the Nonconformist Academies rather than the universities, as more modern subjects were taught in the former, including, in particular, a great deal of science. Some of the tutors at the Nonconformists Academies became notabie scientists, such as Joseph Priestley, who taught at the Warrington Academy, and John Dalton, who was a tutor at the Manchester New College. (6-3)

Another contribution concerned certain industries. The historian states:

> The Nonconformists were particularly prominent in the development of the heavy industries, such as the iron industry. Here the Quakers all but dominated the field during the eighteenth century, as the Anglican iron-masters tended to buy estates and become landed gentlemen, leaving the iron industry to the Quakers....One of the more important of the Quaker iron-master families was the Darbys of Coalbrookdale, who invented the method of smelting iron with coke in place of the traditional wood charcoal, which by now had become scarce and costly. The Darby family also developed a method of casting iron in moulds of sand. and they possessed the monopoly of casting steam engine cylinders from 1724 to 1760. Other Nonconformist inventors were the Presbyterian, James Watt, his first partner, John Roebuck, who was an Independent, and John Wilkinson, whose precision boring machine made the Watt engine a commercial success. (6-4)

And, in regard to the decentralization of scientifi: activity, he states:

> The men of the industrial regions with their scientific education at the Non-conformist Academies and their technical interests founded institutions to promote the arts and the sciences in their own localities. (6-5)

Early British Scientific Institutions

Lunar Society

One of the earliest local institutions was founded at Birmingham in 1766. It was called the Lunar Society. The Lunar Society met once a month on the night of the full moon (thus the name was derived) so that the members could find their way home with ease. This society, which included James Watt, Joseph Priestley, Erasmus Darwin (Charles Darwin's grandfather), and its founder, Mathew Boulton, flourished until 1791. Riots against Nonconformists and supporters of the French Revolution chased most of the members out of Birmingham and the Lunar Society came to an end.

Manchester Society

Two other important provincial scientific institutions were the Manchester Literary and Philosophical Society

(1781) and the Philosophical Society of Edinburgh (1783). The Manchester Society resulted from a meeting of scientists and industrialists. Papers read or submitted to the society were published from 1785.

In its early days, the Society was greatly concerned with the science of chemistry, a subject of importance in a locality connected with the bleaching and dyeing of textiles. An eminent scientists associated with the Manchester Society was John Dalton, who served as presiding officer from 1817 to 1844. Chemistry was considered as a separate and special topic in the Manchester Society Constitution along with natural philosophy, literature, civil law, politics, ommerce, and the arts. This society was the forerunner of other 19th Century societies in England.

Philosophical Society of Edinburgh

The Philosophical Society of Edinburgh received a royal charter in 1783. Among its members was David Hume (1711-1776) the philosopher, Adam Smith (1723-1790) the economist, Joseph Black (1728-1797) professor of medicine at Edinburgh, and James Hutton (1726-1797) a pioneering geologist. This society, like the Manchester Society, was in touch with the industrial development of the time. But the Scot scientists of the 18th Century were more concerned with theoretical aspects. Some of its members criticized the failure of the English to utilize French theoretical work. These two societies were able to survive the 1791 riots and became important institutions in later English science.

At the close of the century the two main centers of scientific activity, England and France, became similar in their approach. The English became more theoretical and the French more empirical. However, the character of all science was changing; a new concept of science in society was emerging. The characteristics of the old science and society relationship disappeared as nation after nation utilized science on a greater scale. In the next part of this chapter we will consider the countries which have been most prominent in this movement.

Nationalization of Science

Before 1800, natural philosophers of France and Britain had been the most prominent. As we have seen, their activities tended to be complementary. The British supplied most of the empirical work and the French the theoretical interpretations. In the early 1800's, the French became the leaders of world science. However, by 1860, the British again assumed the lead for a short period of time.

The beginning of the 20th Century was marked by the rise to eminence of German science, tending to remain supreme until the end of World War II. Following World War I and up to the present, two other nations started to challenge and finally outstripped German science. These two nations, the United States and the Soviet Union, have been competing with each other for prominence in pure and applied science.

Notice how this chapter on science has changed from discussion of individuals to the discussion of nations. This change in presentation is a reflection of how science has changed. The individual scientist is still the important entity of scientific activity, but the framework under which he practices science has changed tremendously. We will look at several countries to illustrate the change of science during the 19th Century and part of the 20th Century.

British Science

The growth of scientific activity continued to become centered in the provinces. This was reflected in the great increase in the number of provincial literary and philosophical societies. At the close of the 1800's, over 100 such societies had been founded. Every important town had its own scientific institution composed of amateur scientists, industrialists, and professional men.

The purposes of these societies were mainly (1) the advancement of knowledge and the applications of science, and (2) the improvement of the economy and culture of each region.

Royal Institution

Britain did have many amateur associations but she lacked facilities to train scientists. Various cities of Britain started developing mechanical institutes which eventually evolved into technical colleges. However, Count Rumford (who had emigrated to England during the American War of Independence) pressed for the formation of a national institute. He raised funds for the Royal Institution of Great Britain, founded in London in 1800.

Humphrey Davy and an early lecturer. He designed his lectures to appeal to the wealthy patrons. Davy also carried out research for various influential agencies so that the Royal Institution was able to pay its way. Davy invented the miner's safety lamp when he was conducting research for the Society for the Study and Prevention of Mine Explosions. So the Royal Institute became a research facility rather than a national mechanics institute. The change of the institute toward a professional character disturbed Count Rumford causing him to leave England and live the rest of his life in France.

British Association for the Advancement of Science

Science was becoming more complex. Experimental research was becoming costly because of the need for apparatus. The need for educational and research facilities increased. Humphrey Davy was writing a book calling attention to this dilemma when he died (1828). Charles Babbage, a pioneer and inventor of early computers, took up the call for an association of interested persons to promote science in Britain. He also asked for government assistance, but the government showed little concern.

In 1831, The British Association for the Advancement of Science was founded. The idea for the association came from a national congress of German scientists which Babbage attended and from the writings of Francis Bacon who had suggested the idea in 1626.

The association was active in reforming higher education but failed to get financial support from the government. The British Association financed a small amount of research with the physical sciences getting most of the money. It also supported research in biology, medicine, agriculture, and geology, but gave them much less support. Geology received more money when it was found to be of great practical use in the location of coal and metal ores. Anthropology was heavily subsidized during the 1880's when Britain became involved in the study and control of native tribes of Egypt, India, and Australia.

British science was able to survive through the patronage of private individuals and societies. The necessities of World War I (1914-1918) brought the matter of government-supported science to national attention. Gas warfare, anti-submarine warfare, and modern warfare in general, awakened Britain to the need for national support of science. In 1917, Britain founded the Department of Scientific and Industrial Research and the Agricultural and Medical Research Councils were established a few years later. Besides military interests, such national agencies also promoted the improvement of industry, agriculture, and medicine and have provided the bulk of the financial support for scientific research. Since World War I, Britain has maintained a staff of well-trained scientists.

French Science

During the French Revolution, the scientists of France found their activities directed toward practical problems. This gave them greater preoccupation with experimentation. Their first major project was the standardization of weights and measures throughout the country for which the Paris Academy of Sciences set up a committee in 1790. In the following year the meter was recommended as the standard of length (it was finally adopted as the standard of measure in 1799).

In the midst of this project, the French Revolution took a radical turn. The Paris Academy of Sciences was closed along with many of the other old institutions. Lavoisier was executed for his tax-collecting enterprises. But the French had great need of science for the defense of the country. So the French leaders called upon scientists to meet the technical needs of France.

The scientists investigated ways of improving France's military stature. Gaspard Monge (1746-1818) investigated the casting and boring of cannons and became Minister of the Navy. Lazare Carnot (1753-1823) was made Minister of War. His contributions earned him the title of "Organizer of Victory." Antoine Fourcroy (1755-1816), Claude L. Bertholett (1748-1822), and Guyton de Morveau (1737-1816)--all chemists--investigated the synthetic preparation of saltpeter (KNO_3), an important ingredient of gunpowder.

French Scientific Institutions

Such contributions showed that science was of value to the national government. So the old institutions were reformed and new institutions were established. In 1795 the Institute of France was founded. This institute was composed of three sections, one of which was the old Academy of Sciences. The scientific section of the

Institute of France consisted of 60 members each having equal status. The members were salaried officials of the state, the same as the members of the old Academy of Sciences.

Institutions were established to train scientists. The Ecole Polytechnique, devoted to science research and education in France, was established in 1794. The Polytechnique flourished from the start. It had 400 pupils and a staff of leading scientists. Such men as Laplace, Berthollet, Guy-Lussac, Dulong, and Petit were associated with the Ecole Polytechnique, either as pupils or teachers.

Several military, medical, and technical colleges were formed under Napoleon. Fourcroy, the chemist, was made Minister of Public Instruction and was responsible for the founding of these colleges. Napoleon encouraged applied science by offering prizes for useful inventions and discoveries. French science became more practical and experimental. During Napoleon's reign, the techniques of French industries were advanced.

When Napoleon was removed from power, the Bourbons temporarily closed the Ecole Polytechnique. It was accused of being too materialistic and revolutionary. However, the polytechnique and mathematical physicists had started a tradition which was continued in 19th Century France. One bad effect of this tradition was that science became concentrated in the Paris schools. The provinces of France lost their talented scientists to Paris. The French Association for the Advancement of Science was founded in 1870 in an effort to decentralize French science but was only partly successful because French science is still concentrated in the Paris schools.

German Science

While Britain and France led the world in science, the Germans still followed the science traditions established by her 16th Century scientists. The Germanic people were divided into a number of minor principalities. In contrast, Britain and France were established nations. The Germans had an active interest in science but they produced nothing that was new. The following statement by a science historian is an example:

> ...of ninety or so scientific journals founded before 1815, fifty-seven were German, nine were Italian, fifteen were French, and eleven were English, whilst America, Switzerland, Sweden, Holland, and Belgium had one each. For such a number of scientific journals to be founded, there must have been a considerable interest in science..., but it seems that this interest was not active enough to produce markedly novel advances. (6-6)

Even though Germany was not pioneering in science in the early 19th Century she was a sleeping giant.

German Scientific Institutions

In 1817, the philosopher Lorenz Oken founded a scientific and literary journal called Isis. This journal became the vehicle for the spread of science and national sentiment. In 1821, Oken called for a national congress of German-speaking doctors and scientists. The purpose of the national congress, according to Oken, was for

> ...the good of science and the well being and honor of the Fatherland. (6-7)

The first meeting of the congress was in Leipzig in 1822. This congress was called the Deutscher Naturforscher Versammlung. The first congress consisted of 20 active scientists and about 60 nonscientist guests. To Oken the meeting was:

> ...the spiritual symbol of the unity of the German people. (6-8)

The ruling princes of the various German states were suspicious of the first national congress. The people attending the congress refused to reveal their names as they were afraid of reprisal from their governments. The Prussian government was the first to see the value of the national science congresses. They visualized the congresses as a controlled force for German unity, so in 1828 the Prussians extended their patronage to the meetings. As a consequence, the German government gained more and more control over the scientific congresses. Under German governmental control, many meetings were hosted by states. The president and secretary of the congress were often appointed by the government. At the 1828 meeting, Alexander Von Humboldt, the appointed president said:

> How can our national unity be more forcibly expressed than by this association? ...Beneath the protection of noble princes this assembly has yearly grown in interest and importance. Every element of disunion which difference of religion or form of government can occasion is laid aside here. Germany manifests herself, as it were, in her intellectual unity...and...this feeling of unity can never weaken in any of us the bonds that endear us to the religion, the constitution, and the laws of our country. (6-9)

This 1828 meeting was attended by foreigners who returned to their countries and suggested the foundation of similar institutions. These suggestions led to the formation of the British Association for the Advancement of Science (founded 1831), the All-Italy Association of Science (1839), The American Association for the Advancement of Science (1849), and the French Association for the Advancement of Science (1872). However, the French, British, and American associations did not achieve the national influence of the German congresses. The All-Italy association was nationalized in a manner similar to the German society but its history was interrupted by the civil uprisings. It was not until 1907 that the All-Italy

Association was firmly established with the formation of the Italian Association for the Advancement of Science.

During the unification of Germany under the Junkers (Prussian aristocrats) the nationalism and liberal spirit of the congress was lost. The scientists split into pro and anti-Junker camps. However, after the unification of Germany by Bismarck and the Franco-Prussian war, science again prospered. It became an ever-increasing national resource. For example, the German chemists teamed with industrialists to make Germany the leader in the production of dyes, pharmaceuticals, and fertilizers. The German science became institutionalized at the national level. As a science historian states:

> In Germany....there was real enthusiasm for the chemical industry.... Germany, an ambitious nation under Bismarck, hoped to become preeminent in industries closely allied with science. While its chemical firms arose from small beginnings, the economic climate was such that they could become veritable giants by the end of the century. Adequate financing, vigorous approach to sales, farsighted management, a favorable patent policy, and mutually agreeable competitive arrangements enabled German industry to flourish. Scientific education was given sympathetic support by state and industry. Well-trained chemists were available to carry on the research necessary to master the indigo problem and to expand greatly the knowledge of useful compounds. By 1897 there were 4,000 chemists active outside the academic field in Germany. (6-10)

This drive for world dominance in science continued through the first part of the 20th Century. After World War I, some German scientists advocated doctrines that later came into prominence under the national socialists. They were advocating the superiority of the German race and its attainments. When the National Socialists (NAZI Party) came to power in 1933, a large number of the scientists condoned its policies and actions. They supported Hitler's drive for a greater Germany. Some scientists did not participate in the NAZI drive for greatness but they were in the minority.

However, this German nationalism began to weaken German science. A basic conflict existed between science and the national socialists. The NAZI's held that privileged persons within the German race could achieve a superior understanding of nature by intuition, while most scientists held that all observers were equal. Einstein's theory of relativity is based on the assumption that all men are equal and equivalent observers, so his theory was not accepted by many German scientists.

The privileged intuition doctrine led to a decline in theoretical science in Germany, in particular physics. The enrollment of students in the theoretical physical sciences dropped from about 12,000 (in 1932) to about 5,000 (in 1936). Student enrollment in applied sciences also dropped but not so drastically. The quality of higher education declined. Scientists who were politically or racially unacceptable were removed from their posts. Many of the replacement instructors were appointed for their political sympathy for national socialism rather than for their teaching capabilities.

The NAZI's deplored theoretical science which was claimed to be a Jewish product. Theoretical science tended to contradict the tenets of national-socialism and its practice was discouraged. Biologists and anthropologists presented evidence that contradicted the NAZI racial theory, but these scientific results were ignored.

At the start of NAZI Germany's push for world domination, the spirit of national socialism infected German scientists. Many leading scientists began to view themselves as the great men and leaders of science. They considered German science and themselves to be above the normal community of science. They no longer considered scientists from other countries to be their equal. The rise to power of the NAZI's led to the revival of astrological horoscoping and more important, the decline of fundamental research and applications of science. Germany is a prime example of a science and society interrelationship that was headed for decline. As a science and historian states:

> A society engendering and sustained by values which are antagonistic to those

> of science will become historically less and less effective in the modern world. (6 ..)

United States Science

The United States derived its scientific tradition from England. However, with the movement for independence, American science increased in intellectual activity. Probably the most important American scientist was Benjamin Franklin (1706-1790). Franklin, who showed that lightning was electrical in character, was also a leader in the American Revolution. Another American, Benjamin Thompson, was sympathetic to the English point of view and during the war for independence he emigrated to England. In England, he was known as Count Rumford. He served the English by founding the Royal Institution and the Prussians as director of their munitions works. But he did not contribute to American science.

Science Under Jefferson

Our third President, Thomas Jefferson, was a cientist in a general sense. He sought knowledge and liked to see it applied. As one political scientist says:

> He had great faith in the usefulness of science, not only of practical inventions but researches as esoteric as paleontology (study of fossils). He believed that science had no national

> bounds and that its followers "form a great fraternity spreading over the whole earth, and their correspondence is never interrupted by any civilized nation." (6-12)

Jefferson' administration supported various scientific investigations. He offered equipment to Charles Wilson Peale to excavate bones of some mammoths that Peale had discovered. Jefferson made the Lewis and Clark expedition in part a scientific investigation. He desired information about Indians, botany, natural history, and astronomy. So he sent Captain Lewis to the American Philosophical Society in Philadelphia to learn how to make observations and collect specimens. The Lewis and Clark expedition was financed from military appropriation. This expedition was the first research supported by the War Department (now part of the Department of Defense).

During Jefferson's Presidency, research grew at the state and national level. Jefferson's leadership set a precedent; science in the service of our country was established. However, science was viewed primarily for its value in applied research. Therefore, science investigations were primarily toward the development of practical devices. A the same time, our country's pioneers placed great value on men associated with useful occupations. A theoretical scientists was considered an idler. The scientists were practical men with an outlook toward useful products.

The scientific tradition of America has been mainly utilitarian in character. The United States, in the early days, was a country rich in natural resources but she was sparse in population. This condition placed emphasis on the development of labor-saving devices, and upon methods of communication and transportation. This tradition was reflected in the founding of the U.S. Military Academy (West Point, 1802)--originally an apprentice school for the Army Corps of Engineers.

Jefferson failed in an attempt to establish a national university for science education and research. The states were hostile to any type of nationally organized agency. They adamantly upheld the doctrine of states' rights. The U.S. Congress, which reflected this states' rights attitude, blocked the organization of any scientific institution of national proportions. One exception was the founding of the Smithsonian Institute at the bequest of a foreigner.

United States Science Institutions

Count Rumford went to England and founded the Royal Institution. Coincidentally, an Englishman, James Smithson (1765-1828), provided the funds for the institute bearing his name. Smithson, an English nobleman, was dissatisfied with the English aristocracy and bequeathed his fortune to the American government. The stipulation for the bequest was the establishment of a scientific institution. Congress established the Smithsonian Institute in the 1840's and this act became the first official recognition of science by the U. S. Congress.

United States scientists lobbied for better science and government relations. They felt that science could be used for the improvement of our nation. They finally won some national recognition when a national academy was founded. The National Academy of Sciences,founded in 1863 by Congress, was organized as a self-perpetuating body of scientists who did research in various fields of science. They were to investigate scientific problems when called upon by Congress. However, the scientists were not called upon for many problems.

Following the Civil War, the governmental attitude shifted from "states' rights" to the "general welfare." The government--with a freer hand--gave assistance to industrial systems by setting up permanent scientific agencies. The Department of Agriculture, which achieved cabinet status in 1889, accumulated a number of bureaus responsible for the study of agricultural problems. Agricultural research was organized around the federal structure of the nation by the Hatch Act in 1887.

The pre-World War I era was marked by the Congressional establishment of various agencies to meet the needs of a growing industrial society. The National Bureau of Standards was set up in 1901, the Public Health Service in 1912, and the National Advisory Committee for Aeronautics in 1915. The government set up these agencies to provide services and to promote regulation. The Pure Food and Drug Act, primarily a reaction to poor food processing practices, made use of science in its administration.

World War I revealed a need for greater research and development. In the field of military weapons we were far behind. In 1915, the Navy appointed Thomas Edison to head a Naval Consulting Board which was ineffective due to insufficient funds. Edison advised the Navy to hire a physicist in case they needed someone to do calculations.

The National Academy of Sciences--almost inactive since the Civil War--agitated for greater use of its members. So President Woodrow Wilson created a National Research Council (NRC) as a branch of the Academy. The NRC did not become active until January, 1918 but it cooperated with the armed forces, the Bureau of Mines, and the Bureau of Standards in extensive projects, especially gas warfare and optics.

The close cooperation of university, industrial, and government scientists engendered by the war returned to pre-World War I levels following the armistice in Europe. The 1920's were a low period in the development of government science. The NRC was given a permanent status but suffered from lack of funds. The Armed Forces appropriations were cut to a minimum. America "kept cool" with Coolidge. President Herbert Hoover--an internationally known engineer--tried to establish a National Research Fund for pure science, but failed in his efforts.

As the United States approached 1939, government agencies were still using science as a tool primarily for technical needs. The National Research Council published a report, Research--A National Resource which clearly implied that discoveries made possible by government supported research might provide the stimulus needed by the national economy. The committee recommended closer ties between government and scientists by sponsoring more research. This 1938 report, which went almost completely unnoticed, was very farsighted as subsequent events have shown.

Russian Science

The scientific tradition of Russian is very similar to that of France. The state government had almost absolute control of all natural resources. This situation encouraged a spirit of criticism and revolt. In the 19th Century, Russian intellectuals used science to criticize beliefs that were prevalent in the Russian society.

Russian science was theoretical and resembled French science. In fact, much Russian scientific knowledge originated in France. The St. Petersburg Academy of Sciences, founded by Peter the Great (1724), was modeled after the Paris Academy of Sciences. Many French scholars taught at the Academy during the 18th Century. For many years, the Academy was staffed by scholars from France, Switzerland, and Germany. Later, local scientific societies were formed in cooperation with the local universities (Moscow, Kazan, and Kiev). During the 18th and 19th Century, Russia produced some notable theoretical scientists. Two of special interest are Lomonosov (1711-1765), an 18th Century advocate for an atomic theory who had his theories quoted by Lavoisier; and Dimitri Mendeleef (1834-1907), whose work on the development of the chemical periodic table provided a theoretical guide to the search for new elements.

During the Russian Revolution (1918), science was directed towards more practical problems. The revolutionaries took great pains to develop a system of science education. Their plans were not fulfilled until the 1930's but by the end of the 1920's, 91 universities had a total of about 100,000 students being trained in science. This support of science by the Soviet government has increased. The respect for Soviet science is indicated by attention given to her scientific publications. Today, the United States, Britain, France, and other countries translate the main Soviet scientific periodicals into their native languages.

But Soviet science has always been handicapped by the philosophy of the revolution. Dialectical materialism, which originated with Karl Marx (1820-1895) in Dialectics of Nature, has restricted the spirit of science in the Soviet Union. This dilemma has often resulted in the attack on some generally accepted theories of science.

The most notable controversy centered around Mendel's theories of genetics. T. D. Lysenko, a Soviet biologist, developed the theory that the hereditary system of an individual could be changed during early stages of growth. For example, in plants the characteristics of offspring--the seed and new plant--could not be determined by knowing the characteristics of the parent plants. This theory (indeterminate genetics) was made to agree with certain assumptions of dialectical materialism, but disagreed with Mendel's theories (determinate genetics). Lysenko and his school of thought attacked Mendel's theories. This controversy started in 1934 and lasted for many years. In 1948, the Lysenko group gained control of the Lenin Academy of Agricultural Sciences and the Mendelian school was temporarily disbanded.

However, this controversy (along with others) soon lost importance when practical Soviet officials began to appreciate the contribution of science to the nation. They saw that economic advancement depended upon the development of new and more accurate theories in the lab and the field. Even though Soviet scientists do not have complete freedom, their work is less hampered by philosophical discussions of theories no longer at the frontiers of knowledge.

In these six chapters we have considered science and its relation to society at several times in history. We have looked at Mesopotamian, Egyptian, Greek, and Roman science. We have considered the contributions of the Christian and Muslim religions. We have seen science rise after a long decline and steadily progress to new and different characteristics. Science, as we have seen, has gone from the work of priestly scribes, to men of leisure (scholars), to men who wrote encyclopedias, to amateurs, and finally, professional scientists. Science has gone from an individual to a national endeavor in about five thousand years. Where it will go from this point no one knows but we do know that science holds an important position in this world.

We have discussed the birth of the concept of atoms. In the next two sections we will again take up the study of the atom. We will not study the theories of atomic structure but confine ourselves to the phenomenon known as radioactivity and the many ramifications of this discovery. We will look at the scientists--in particular

American and German scientists--in greater detail as we consider the race to develop a nuclear bomb. In Section II we will take a close look at these events and the events that followed.

The study of the interrelationship of science and society is a difficult task because you must rely on recorded history for your information. In Section III you will not have to rely on recorded history for your information because the events considered are quite recent. You will be reading about events that have taken place within the last 25 years. If you could go back in time to some point in the last three decades to correct some event where would you like to be? Before you answer this question read this entire unit.

THE DEVELOPMENT OF ATOMIC ENERGY
AND ITS SOCIAL IMPLICATIONS

SECTION II.
EXCESS FAITH IN SCIENCE BY SOCIETY (SCIENTISM)

CHAPTER VII. FROM RADIOACTIVITY TO THE NEUTRON

In the last section we looked at science during several periods of time and found that the trend over the centuries has been from individual to national science with the support of science gradually falling on national governments. We are now to consider the thought that, although the scientist appears to be very important today, he has become lost in a complex social and scientific community.

How has this come about? There are probably many reasons--the main one being need. Society needs science and the scientist to help with its many problems. Unfortunately, people think that the scientist can solve any problem if given enough time and materials. But can he? Science has been and can continue to be successful but it has neither the capability nor wisdom to solve all problems.

Sometimes science helps in the solution of a problem but in the process creates new ones. A good example is the scientific work that led to the utilization of nuclear energy. Science and society combined forces to harness the energy of the atom but in doing so they created a great menace. Since then, science and society have been searching for means to reduce the menace--without success.

In this section we will look at the events that led to the discovery and release of nuclear energy. We will start with the early chance discoveries that led to further study of the atom. This will be followed by a consideration of about 40 years of nuclear science research, the high point of which was the discovery of nuclear fission. Next, we will look at events that caused scientists and society to develop the atom bomb. Finally, we will consider the way science and society interacted to launch us into a new age--The Atomic Age.

Serendipity and Nuclear Science

There is an old tale about three princes of Serendip (former name for Ceylon) who were always discovering--by chance or by wisdom--things that they did not seek. This Persian tale prompted Horace Walpole to coin the word "serendipity" meaning "the gift of finding valuable things not sought for."

Numerous scientists have sought to find one thing but have discovered something else. This gift has probably often been missed because the observer was not prepared to recognize somthing new and different. Columbus is an example of an observer not prepared to recognize his serendipity. He was looking for India and thought that he had found it. As Louis Pasteur once stated, "Chance favors the prepared mind."

Serendipity has been of occassional importance in nuclear science. But scientists did not simply go into their laboratories and discover atomic energy. They spent many years studying evidence, occassionally finding something new. Roentgen and Becquerel were able to take advantage of their serendipity but other nuclear scientists missed making important discoveries because they were not prepared. The discovery of nuclear fission was delayed five years because science was not prepared to understand this new phenomenon.

Discovery of X-Rays

In 1895, society in western Europe and America was moving at a leisurely and peaceful pace. It was late in the Victorian Era and the new technology had not begun. Some automobiles had been produced but since their use was restricted by many laws, transportation was mainly by horse and buggy. One scientist describes the situation in England:

> The "gasoline buggy" had made its noisy appearance--Ford had built his first car two years previously--but here in England we were protected against this horseless monstrosity by a paternal Government's Red Flag Act. This solicitous act decreed that no self-propelled vehicle should dare venture on the public highway unless

> it were preceeded by a man carrying a warning red flag by day and a cautionary red light by night. The speed of these perilous chariots was limited to a severe four miles per hour. (7-1)

Flying at this time consisted of brave souls jumping off buildings flapping home-made wings. The Wright brothers, Wilbur and Orville, made their first successful flight in 1903. People did not have radios, and movie projectors--invented in 1894--were just catching the public fancy. The times were not at all like the hustle and bustle of today.

Most of the scientific world drew comfort and security from their scientific accomplishments. Many scientists thought that all scientific knowledge was known. They merely wanted to get better measurements for better accuracy and thus more accurate knowledge. The atom, for example, was considered to be a hard sphere. This idea, formulated by Democritus (C. 500 B.C.) and modified by John Dalton (about 1808), was gradually becoming accepted by a large number of people. To most men of science (except the physicists who did not have need for the concept of the atom at this time), the atom was the ultimate particle of matter.

It was this type of world that received the shattering announcement from a little known German professor, Wilhelm Konrad Roentgen (University of Wurzburg) that he had discovered a new kind of invisible ray. This ray could pass through clothing, skin, and flesh and cast the shadows of bones on a photographic plate. How did this discovery come about?

It was Friday, November 8, 1895 and Roentgen was working with cathode rays (known today as electrons) in his laboratory. He was working with a special tube (Crooke's tube) which emitted cathode rays (electrons) that caused the surface of certain objects they struck to glow in the dark. Roentgen wanted total darkness so he enclosed the Crooke's tube in a large cardboard box.

As he was checking the effect of the rays on chemicals in the darkened laboratory he noticed that a piece of paper at the corner of his laboratory bench was glowing. The paper was chemically treated but cathode rays were not striking it. Roentgen wondered, "What is the cause?" He knew that cathode rays could not pass through the cardboard so he was certain that the glow was not due to the cathode rays. If cathode rays were not the cause then there had to be other rays. What were the rays? Roentgen did not know so he called these mysterious rays, "x-rays."

He tested the penetrating power of these rays by putting various objects between the Crooke's tube and the chemically coated paper (the coating was barium platinocyanide). He placed all sorts of opaque materials such as wood, thin sheets of aluminum, and also his hand in front of the Crooke's tube. They rays went through practically everything. They were, however, completely stopped by thin lead plates and partially stopped by the bones in his hand.

It was this discovery that Roentgen presented on the 28th of December to the Physical Medical Society of Wurzburg. From this presentation, the discovery of x-rays received world-wide publicity. Newspapers misspelled Roentgen's name (Routgen was used), but they gave the discovery special headlines.

Can you imagine the excitement this announcement caused? Its impact was tremendous. Medicine quickly realized the importance of x-rays. Doctors did not know what they were but they requested copies of Roentgen's tube. They planned to use it to search for broken bones and foreign objects lodged in the flesh.

The ordinary citizen feared this new phenomenon and many stories and rumors were circulated. Statements such as the one that follows were common:

> Someone using special x-ray glasses can look through walls and doors and see what he is not supposed to see. (7-2)

The women of the period were aghast at the opportunities these rays opened to unscrupulous men. Various kinds of x-ray-proof products were sold. One of them was x-ray-proof undergarments made of lead. They were advertised in a newspaper as follows:

> Wear it under your clothes so that the x-rays cannot touch you. (7-3)

An assemblyman in New Jersey introduced a bill in the House of Representatives which prohibited the use of x-rays in opera glasses at theaters. A London newspaper editorialized as follows:

> We are sick of Roentgen rays. Perhaps the best thing would be for all civilized nations to combine to burn all the Roentgen rays, to execute all the discoverers, and to corner all the equipment in the world and to whelm it in the middle of the ocean. Let the fish contemplate each other's bones if they like, but not us. (7-4)

Even the poets were busy with Roentgen rays. The following verse appeared in Life magazine:

> She is so tall, so slender, and her bones--
> Those frail phosphates, those carbonates of lime,
> Are well produced by cathode rays sublime--
> By oscillations, amperes and by ohms,
> Her dorsal vertebraie are not concealed
> By her epidermis, but are well revealed.
>
> Around her ribs, those beautious twenty-four,
> Her flesh a halo makes, misty in line,
> Her noseless, eyeless, face looks into mine,
> And I but whisper "Sweetheart, je t'adore,"
> Her white and gleaming teeth at me do laugh,
> Ah! Lovely, cruel, sweet cathodagraph!
> (7-5)

Probably the most popular poem appeared in a photographic magazine (Photography):

The Röntgen Rays, the Röntgen Rays,
What is this craze,
The town's ablaze,
With the new phase
Of x-rays ways.

I'm full of daze,
Shock and amaze,
For nowadays,
I hear they'll gaze,
Thro' cloak and gown--and even stays,
These naughty, naughty Röntgen Rays.
(7-6)

Thus, an accidental discovery caused a revolution in medical treatment. It also caused much concern and anxiety among the laymen of the world. The discovery of x-rays which asked more questions than were answered led to further scientific investigations. Later investigations attempted to answer questions such as: What are x-rays made of? Where do x-rays come from? But the results of further studies were as unexpected as the glowing slip of paper.

Discovery of Radioactivity

When the news about x-rays reached Paris, Antoine Henri Becquerel gave the matter close attention. He was fascinated by the mystery of this new ray. To Becquerel, x-rays held promise as a tool for probing nature. He thought, "Perhaps I can find another way to produce these mysterious rays." He was concerned with one thing in particular--the glowing spot on the glass of the Crooke's tube. Becquerel knew that the glowing spot was where the cathode rays hit the glass. He wondered if the glow that was responsible for the x-rays was the same as the phenomenon known as fluorescence.

Becquerel's first task was to find out whether the phenomenon known as fluorescence and the newly discovered x-rays were related. The experiment that he performed was very simple. He exposed a fluorescent substance to ordinary sunlight until it fluoresced (glowed). Then he put this substance on a photographic plate wrapped in light-proof paper. When he developed the photographic plate he found that it had been fogged (exposed). So he assumed that the x-rays from the fluorescent sample exposed the plate.

The results of his original experiment thrilled Becquerel. He was seeking knowledge and nature revealed one of her secrets. For upon developing the blackened plate he could only conclude that the exposure was due to x-rays. There was no doubt in his mind that strong fluorescence could produce x-rays. All you had to do was to expose a fluorescent substance to sunlight and it would give off x-rays.

Becquerel was anxious to report his results. On February 24, 1896 he announced that he had produced some of the mysterious rays. But, not content to leave the problem, he planned to repeat the experiment a few more times. He put a crystal of a fluorescent substance on top of a photographic plate which was covered with black paper. But he could not repeat the experiment. The skies over Paris were cloudy so he postponed the experiment and waited for a sunny day.

About a week later, Becquerel was ready to repeat the experiment but he was not sure of the condition of the photographic plate. So he developed the plate without repeating the experiment. As he developed the plate he could see black images. These images were similar to those of his previous experiment, but the crystals had not been exposed to sunlight. The crystals had lain all the while in a desk drawer and could not have become fluorescent. This was another new and different mysterious ray. It was more confusing than the discovery of x-rays. Imagine! A crystal of some substance giving off rays that were not due to electricity or fluorescence.

Becquerel repeated the experiment several times, making sure that the fluorescent crystal and photographic plate did not come in contact with light. The results were the same as before: large areas of the plate were exposed. The images of crystals could be seen on the photographic plate. How had this come about?

Becquerel had been carrying on the study of fluorescence started by his grandfather and father when Roentgen discovered x-rays. He had a large supply of crystals that exhibited fluorescence--the collection had been gathered by his father and grandfather. Out of this large collection he chose potassium uranyl sulfate (a uranium-bearing compound). Why did he pick uranium salt? Maybe because it exhibits strong fluorescence. Was it some other hunch? Intuition? Or pure chance? No one knows but this choice must be considered one of the strangest sets of coincidences in science. Becquerel had chosen a salt containing the only naturally occurring atomic fuel--uranium.

Further experiments revealed that the rays (called Becquerel rays at first) were not affected by external conditions. Whether in or out of sunlight, the uranium-bearing crystals gave off the same amount of radiation. In addition, the radiation did not appear to diminish in strength. At that time, Becquerel found that only uranium compounds gave this strange radiation. In fact, all his experimentation pointed to one constant thing--the presence of uranium.

He tested the radiation in the crystals, he dissolved the crystals in water, he exposed them to bright light, and he put them in a dark place. The results were always the same. The element uranium was the source of these rays. Later, Becquerel was able to test some pure uranium metal. He found that the photographic plate was more exposed than every before. Without a doubt, uranium was the source of these radiations.

What had Becquerel discovered? The phenomenon we call "radioactivity." However, this discovery did not cause the same excitement that x-rays had. It did not give pictures of bones and was not as fascinating as x-rays. Nobody except Becquerel saw any profit in studying these mysterious new rays. His findings were neglected for a year and a half until Marie Curie was attracted to them.

The exposure of a photographic plate requires energy. It is impossible to take photographs without some form of energy. Becquerel knew this fact but he could not explain the energy source in uranium. He was willing to look for this energy source but he needed help. So he went to see two of his friends, Pierre Curie and his wife, Marie Sklowdowska Curie. Dr. Pierre Curie was a physicist at Ecole Polytechnique and Marie was a student working toward an advanced degree in chemistry. Becquerel proposed the idea of a research team to study this new radiation. Little did he dream that the decision of the Curies would one day change the face of much of science.

The Curies' Search

After Becquerel's discussion about radioactivity, Marie Curie became curious about the penetrating rays. Henri Becquerel suggested that Marie study other mineral crystals for this radiation. She followed his suggestion, tested many other minerals for radioactivity, and finally found that only the minerals with the elements uranium and thorium exhibited radioactivity.

Her work was not easy. She was not well received by the male-dominated scientific establishment. She could not get a well-equipped laboratory. Marie Curie had to settle for an old wooden shack which had been used as a dissecting room by the Faculty of Medicine of Sorbonne. It had been abandoned a few years before because it was not fit to house the cadavers. The roof leaked and there was no ventillating system. Much of the work was done outdoors in a yard. Marie later wrote:

> It was in this miserable old shed that the best and happiest years of our lives were spent, entirely consecrated to work. (7-7)

Marie Curie found that the amount of fogging (exposure) of a photographic plate was dependent upon the amount of uranium or thorium present. The more uranium or thorium the more blackened the plate became. She also found that the uranium extracted from the pitchblende did not account for all the pitchblende's radioactivity. The radioactivity of the uranium was less than that of the original pitchblende.

In fact, the radioactivity of the residue was greater than the activity of the extracted uranium. Marie Curie suspected that there might be another radioactive element besides uranium and thorium.

After observing that the residue gave off more powerful radiations than the uranium, Marie sought to find this new element. She broke the pitchblende residue into various parts by chemical extraction (fractional crystallization). Then she searched among the fractions for the new element, looking for its radioactive power. The first fraction had a more intense radiation than the uranium, so Marie assumed that this was a new element. She named the new element "polonium" after her native country, Poland, which she left in 1892 because she wanted to be free of Czarist oppression. She announced her findings at the April, 1898 meeting of the French Academy of Science. Marie was criticized for basing her report on such a small amount of evidence and was advised to start again. The scientists felt that she had made an error.

Marie was in need of help so Pierre gave up his research work and helped Marie with hers. In their joint labors they repeated Marie's previous work. They found radioactivity in the uranium and the polonium fractions and everything was in agreement. But they also found a second fraction that exhibited radioactivity. It was chemically different from polonium. Marie and Pierre could conclude only one thing: pitchblende contained a second unknown radioactive element. They called it "radium."

In a note published in the Proceedings of the French Academy of Science, they reported the discovery of radium. Again, the French scientists were skeptical. They felt that the Curies did not have enough proof. The scientists advised them to isolate larger amounts of these elements to verify their results.

So the Curies started on one of the greatest searches of all time. They were searching for a treasure more precious to them than gold. They were looking for two mysterious and extremely rare elements. The only assistance that the elements gave them was their steady stream of signals. What the Curies had to get was a few grains of "polonium" and "radium" from a mountain of ore.

In early 1899, the Austrian government gave them a ton of pitchblende residue. The Curies began to separate the polonium and radium from the rest of the pitchblende. However, they decided to concentrate their efforts on the search for radium--the more abundant fraction. This work occupied four years (1898-1902) of their lives. They had to heat the pitchblende residue to break down the rock. The ventilation in the cadaver shed was not very good so all of the heating had to be done outside in a courtyard.

Marie Curie had to mix the material in a metal cauldron with a large iron stirrer. As she stated:

> I sometimes passed the whole day stirring a boiling mass with an iron nearly as big as myself. In the evening I was broken with fatigue. (7-8)

After breaking down the rock, they had to separate the minerals and finally the elements in the pitchblende residue. They then tested for radioactivity among the fractions. Gradually, they treated a mountain of pitchblende residue that was yielding a highly concentrated, strongly radioactive solution.

Then, one autumn evening in 1902, an event occurred that Marie Curie was to remember forever. She fed and bathed her four year old daughter, Irene, and put her to bed. Grandfather Curie babysat while Pierre and Marie went to the cadaver shed to do some work. Eve (Marie's second daughter) describes what happened next:

> ...they arrived in the Rue Lhomond and crossed the little courtyard. Pierre put the key in the lock. The door squeaked, as it had squeaked thousands of times, and admitted them to their realm, to their dream.
>
> "Don't light the lamps!" Marie said in the darkness. Then she added with a little laugh:
>
> "Do you remember the day when you said to me: 'I should like radium to have a beautiful color'?"
>
> The reality was more entrancing than the simple wish of long ago. Radium had something better than 'a beautiful color': it was spontaneously luminous.

> And in the somber shed where, in the absence of cupboards, the precious particles of their tiny glass receivers were placed on tables or on shelves nailed to the wall, their phosphorescent bluish outlines gleamed, suspended in the night.
>
> "Look....Look!" the young woman murmured.
>
> She went forward cautiously, looked for and found a straw-bottomed chair. She sat down in the darkness and silence. Their two faces turned toward the pale glimmering, the mysterious sources of radiation, toward radium--their radium. Her body leaning forward, her head eager, Marie took up again the attitude which had been hers an hour earlier at the bedside of her sleeping child.
>
> Her companion's hand lightly touched her hair.
>
> She was to remember this evening of glow-worms, this magic. (7-9)

The room shimmered from the glow Becquerel had talked about, the fluorescence that had started his search and the hunt for radioactivity. The Curies knew that radioactivity itself was invisible, but they also knew that they were seeing faint light given off by the radioactive rays striking the air around the container. The blue light was due to the treasure of their search: radium chloride crystals. They now had something to establish their claim.

The discovery of radium, as the Curies found, did not solve a mystery; it uncovered an even greater one. The new question was, "Where did the radioactive element get the energy to send out its rays of light?" They could measure changes in radium energy, but could not measure any changes in the amount of radium. In 1902 no one knew the answer. The unresolved questions were summarized by an American scientist when he stated (as he observed a display of radioactive elements):

> Here are elements that without any outside supply of energy keep on steadily emitting powerful and penetrating rays. Where do these rays come from? Clearly, they must come from the atoms of uranium, thorium, and radium. But if so, what sort of structures can these atoms be? Certainly, they cannot be the old homogeneous balls, they must have structures deep inside that can emit these rays of enormous penetrating power without themselves changing perceptibly. (7-10)

This same thought was going on in the minds of other scientists. But before going into further developments in radioactivity, we should know a little more about Marie Sklowdowska Curie. She was a scientist when it was not fashionable for women to meddle in the activities of men. But her efforts won for her two Nobel Prizes in science, one in physics (1903) and the other in chemistry (1911). She is the <u>only scientist to ever win two Nobel Prizes in science</u>. No other man or woman has accomplished this feat.

In addition, she raised two daughters who became internationally famous. Eve Curie became a very well-known writer, while Irene Joliot-Curie followed her mother in science. In 1934, she and her husband, Frederic Joliot, discovered artificial radioactivity (activity caused by bombarding nonradioactive elements with fast-moving particles) and just missed the discovery of the neutron in 1932 and nuclear fission in 1938. They received the Nobel Prize in 1935 for their work. Marie Curie left a legacy unequalled by any other scientist, man or woman.

The Grand Old Man of Nuclear Science

The light seen by the Curies was soon investigated by the New Zealand-born Ernest Rutherford. While teaching and doing research at McGill University in Montreal, Canada and Manchester and Cambridge Universities in England, he studied the character of radioactivity. The Curies had done much of the chemical work on radium and its related compounds, but many studies of the physical aspects of radioactivity were done by Rutherford and his many associates (he called them "his boys"). Rutherford was an ingenious experimenter who could think of more problems to investigate than could be studied at any one time. As you will see, he did not consider very small deviations as being unimportant.

The Nature of Radioactivity

Rutherford concentrated on the rays emanating from uranium ores--the "Becquerel rays." His experiments proved that the "Becquerel ray" was not one, but three different rays. Rutherford named them Ray 1, Ray 2, and Ray 3. He placed a radioactive source in a hole drilled in a solid lead cube. Then he placed the cube between the poles of a magnet. Rutherford found that Ray 1 and Ray 2 were deflected by the magnet but in opposite directions. The third ray, Ray 3, was not affected by the magnetic or electric forces and was believed to be a true radiation. Rutherford named the three rays after the first three letters in the Greek alphabet: alpha (Ray 1), beta (Ray 2), and gamma (Ray 3).

His next investigation was concerned with the penetrating power of these rays. He found that alpha rays could be blocked by tinfoil from candy bar wrappers. The beta rays could go through ten times as much metal. And gamma rays could go through very thick layers of lead--they can go through as much as 18 inches of steel.

Rutherford also discovered the nature of the different rays. He found that beta rays had characteristics identical to the negatively charged cathode rays--ordinary electrons moving at very high speeds. Rutherford tested the characteristics of beta rays carefully and concluded that they were probably electrons.

Gamma rays were more difficult to identify. It was shown that gamma rays and x-rays were similar. Gamma rays could pass through thicker pieces of material than x-rays and were more powerful. This was no help because nobody knew what x-rays were, so much work had to be done. After a great many experiments and calculations the answer was found. X-rays and gamma rays were similar to visible light only they were more powerful and invisible.

Alpha rays could be deflected by a magnet but in the direction opposite to beta ray deflection. So it was assumed that the alpha particle was postively charged. Measurements showed that alpha particles were heavyweights--they carried four units of weight and two units of charge. Since they could penetrate thin foils, Rutherford devised an ingenious experiment to detect the identity of the alpha particle. He enclosed a bit of radioactive matter in a very thin walled glass tube and sealed this tube in a thick walled glass tube. Alpha particles (as expected) passed through the thin walled glass but not through the thicker glass. Thus, the alpha particles were trapped between the two layers of glass.

Rutherford studied the gaseous material using a discharge tube (like a neon sign tube) and found that the tube glowed. The glow of the gas in the tube was identified as that due to the element helium. The tube contained alpha particles--helium nuclei--that picked up electrons to form neutral helium atoms. "Alpha particles" were found to be ordinary helium atoms without their electrons.

Rutherford received the Nobel Prize in chemistry in 1908 for this work, work that was begun and completed before the beginning of the 20th Century.

Atomic Structure

Experiments before 1900 had revealed the existence of the electron and the proton. It had been shown that all atoms heavier than hydrogen seemed to have several protons and a number of electrons in them. But where were these particles in the atom? Many scientists not only had to accept the concept of the atom but they had to explain its structure. One early explanation visualized the electrons embedded in a mass of positive charge. This model of the atom--the plum pudding atom--was presented by J. J. Thomson in the early 1900's. This model was in vogue for about ten years. As one scientist states:

> The theory of atomic structure current in 1900 might be called the plum-pudding theory. It visualized the structure of the atom as resembling more or less an old-fashioned plum pudding, with the positive charge filling the whole sphere of the atom and the negative electrons embedded in it like the plums in the pudding. This theory was not well supported by evidence. No one had made any investigations of what went on inside the atom; scientists knew only that there were somehow two different kinds of electrical charge in the atom and that postive electricity seemed to account for its mass. (7-11)

Rutherford tackled this problem of atomic structure using alpha particles. He did not have the equipment that is available today. Cyclotrons, Geiger counters, cloud chambers, etc., were not in existence. So Rutherford used what was available. He did his work on atomic structure with a sample of radioactive material, a block of lead, a fluorescent screen (zinc sulfide coated glass), and a protractor--the protractor was similar to the ones used in schools to measure angles.

Rutherford, with the assistance of Hans Geiger (inventor of the Geiger counter), set up an atomic rifle using alpha particles for ammunition. The rifle consisted of a lead block with a hole drilled into it. A radioactive source was placed at the bottom of the hole. The only alpha particles that escaped from the lead block were those that passed straight down the drilled hole. It was quite an ingenious gadget.

Rutherford and Geiger set the rifle so that the alpha particles would hit a piece of gold foil. They expected the alpha particles to pass through the foil because they had passed through thicker foils before. So they set up a fluorescent screen (zinc sulfide on glass) behind the gold foil. When alpha particles hit the zinc sulfide screen they caused little flashes of light. Geiger sat in a darkened room and observed the flashes through a microscope.

He counted the flashes and found what had been expected: alpha particles passed through the foil and struck the screen. Geiger did notice that about one in ten thousand did not pass straight through the foil but were deflected through at a slight angle.

Rutherford set Geiger and Ernest Marsden to studying these deflections. They found that the deflections were indeed present but they found more. They found that some alpha particles were deflected back toward the radioactive source. There weren't very many; about one in twenty thousand was deflected back by the foil.

Now, to most scientists, one in 20,000 is not very significant but to Rutherford it was. From this discovery and almost a year of work Rutherford and "his boys" observed alpha particles doing three things: (1) most passed through the gold foil; (2) a few were deflected through at a slight angle; and (3) an occasional alpha particle bounced back or was sharply deflected. This seemed to show that as far as alpha particles are concerned, gold leaf is mostly empty space. The infrequent deflections also indicate that the gold leaf is mostly empty space. If the gold leaf is mostly empty space then the gold atom must also be mostly empty space. So the Thomson plum-pudding atom was inadequate. A new model or "image" of the atom was necessary.

It was Rutherford who supplied the new model. He suggested that the atom was made of two parts: (1) a very compact positively charged nucleus; and (2) electrons which occupied the region (or space) around the nucleus. He stated that the nucleus accounted for most of the mass and the electron region accounted for most of the volume of the atom. He did not know where the electrons were in the atom but he believed that somehow they were responsible for the volume of the atom. Rutherford visualized the atom as a miniature solar system with the nucleus the sun and the electrons the planets. His model presented questions about the nucleus and the electrons which led to further study. The electron question was answered in part by Niels Bohr (one of Rutherford's "boys"). But this aspect will not be considered any further. It is a story by itself. Our concern is with the nucleus and its energy.

Artificial Transmutation

The mysteries of the nucleus troubled the scientists. But the climate for scientific investigations was threatened by the events leading to World War I. The scientists could not concentrate on their work. In early 1914, researchers knew that their attention would be diverted toward the war effort. In addition, free exchange of ideas between the scientists of European countries was certain to end and so the study of the atom and its nucleus stopped almost completely.

In August, 1914 James Chadwick did not believe the forecast of war. This young assistant of Rutherford had been awarded a scholarship to study under Hans Geiger who was now in Prussia. While English and French people were streaming toward England and France, Chadwick was traveling toward Germany. On August 14, 1914 England declared war on Germany. Chadwick was interned as a civilian prisoner-of-war for the duration of the war.

But Geiger convinced the prison camp director to give Chadwick permission to continue his research. Chadwick was given a small room and some materials at the prison camp and he began experimenting. From time to time, Geiger came around to advise Chadwick and to bring him supplies.

While Chadwick was doing research on radioactivity, Rutherford was preoccupied with government work on submarine warfare. He did spend some time in his laboratory but his attention was divided between two tasks. Once he missed an important war research meeting and worked in his laboratory. His superior reprimanded him for his absence, but Rutherford said that he was working on something that would be more important than World War I. He was talking about "artificial transmutation."

While Rutherford built submarines, Marie Curie worked as a nurse in battlefield hospitals. She introduced the technique of x-ray operations on the battlefield using a Roentgen tube. At the same time, Niels Bohr watched the war from neutral Denmark and helplessly hoped for its conclusion.

Finally, armistice was declared on November 11, 1918.

The attention of nuclear science was again turned toward the atom and its nucleus. Rutherford, who was now at Cambridge, started acquiring a staff of assistants. Chadwick returned to work with Rutherford, full of ideas. The young scientist had spent four years working on radioactivity. He was very interested in the secrets of the nucleus. Some scientists believed that the nucleus was made up of particles and Chadwick was curious to find out. Rutherford and Chadwick started to investigate problems that arose when atoms were torn apart. They thought: if the nucleus consists of particles then a change in the number of particles in the nucleus would change the nucleus. But in order to prove their beliefs they would have to produce changed atoms.

So Rutherford had a long glass cylinder (the glass was very thin) filled with nitrogen gas and added a radioactive source (radium) at one end. The sealed glass cylinder had a thin sheet of metal as a window at the other end. Behind the metal window he placed a zinc sulfide screen and a microscope. The screen and microscope were used to observe flashes of light. With this apparatus he conducted his new experiment.

Chadwick and Rutherford knew that the radium would emit alpha particles. If a speeding alpha particle collided with the nucleus of a nitrogen atom perhaps it would knock other particles (if they existed) out of the nucleus. So they observed the screen through the microscope and counted flashes. They found that <u>three flashes in a million</u> were due to new particles striking the screen. The particles were found to be hydrogen atoms.

Rutherford explained that the speeding alpha particles probably collided with nitrogen atoms and knocked a proton out of the nitrogen nucleus. (He knew that the hydrogen atom contained a proton for its nucleus.) In three cases in a million the alpha particle entered the nitrogen nucleus and changed it into another element. The new element (oxygen) and the proton were products of the collison. That is:

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

(Nitrogen plus an alpha particle yields oxygen plus a proton.)

The researchers were not sure about their results but Rutherford made the following announcement anyway:

> It is difficult to avoid the conclusion that these long-range atoms arising from the collision of alpha particles with nitrogen are probably charged atoms of hydrogen. (7-12)

Rutherford's statement was that of a cautious scientist saying that he and "his boys" had accomplished what alchemists and magicians had attempted for centuries--the transmutation of matter. Man was now able to do what nature has done for billions of years.

This work was the beginning of the artificial transmutation of many elements. In addition, they laid to rest the concept of the "indestructible atom."

Discovery of the Neutron

The information about the nucleus was very confusing. The work before and just after World War I added pieces to the puzzle but that was not enough. A new atom weighing machine--the mass spectrograph--was perfected and it added a new problem: all the atoms of one element did not weigh the same amount. Before World War I, J. J. Thomson found that neon gas had atoms with two different atomic weights. This was suspected by numerous scientists, but had not been proven. In fact, the term isotope was invented for these different atoms of one element before they were found. When the mass spectrograph was improved after World

War I, scientists found that the chemical elements were mixtures of atoms that differed in weight but had the same chemical properties. Early studies showed that every element had isotopes, except hydrogen (later, hydrogen was found to have three isotopes).

The finding of isotopes pointed to a problem that was often ignored. Nobody had answered the questions: how can the positive charges stay together in the nucleus? and how can the nucleus have a mass (or weight) in excess of the protons furnishing the positive charge? For example, lithium has three positive charges but an atomic weight of seven. The question is: how do the three positive charges stay together (they should repel each other) and what is responsible for the four extra units of weight?

One tentative answer was that some protons and electrons were paired in the nucleus. Thus, lithium with an atomic number of three (three positive charges in the nucleus) and an atomic weight of seven had three protons and four proton-electron pairs in the nucleus. But this idea was not acceptable because the proton and electron should annihilate each other. In 1920, Rutherford had suggested the existence of a neutral particle which was not a proton-electron pair. However, many scientists did not hear about this idea or did not pay attention to him.

Much research was done during the 1920's to resolve this question, but the questions remained. In 1930, W. Bothe and H. Becker sent streams of alpha particles at the element beryllium (atomic number = 4, nucleus has four positive charges). They detected a beam of rays from the beryllium with very high penetrating power. The researchers thought they had found rays similar to gamma rays and did not pursue the matter further.

Frederic Joliot and his wife, Irene Joliot-Curie (daughter of Pierre and Marie) did experiments similar to that one performed by Bothe and Becker. They found that the rays coming from the beryllium could pass through sheets of lead which absorbed gamma rays. This showed that the rays were not gamma rays. The Joliot-Curies also found that when these rays entered paraffin (a type of wax), high energy protons were ejected from the wax. This result was unusual and very confusing. It prompted others to investigate.

Chadwick reviewed the experiments of Bothe and Becker and the Joliot-Curies. He repeated the beryllium experiment and found the same results. The rays could not be deflected by a magnet. But Chadwick noticed that the ray did not travel at the speed of light. (They could not be true radiations.) Chadwick continued his work which showed that these neutral rays had a mass (or weight) of about 1 mass unit (almost the same as a proton). He put all the pieces of the puzzle together and concluded that this new phenomenon was the elusive particle Rutherford and "his boys" were looking for. Chadwick was awarded a Nobel Prize in 1935 for the 1932 discovery of the "neutron."

Why was Chadwick successful while others failed? He credited his success to an article he had read. In a 1920 article, Rutherford postulated the existence of a neutral particle with a mass similar to a proton. Chadwick knew about this theory but the others did not. The Joliot-Curies admitted that they had not read Rutherford's article and therefore did not realize what they were observing. Chance favors the prepared mind!

The discovery of the neutron caused a renewed vigor in nuclear science research. This branch of science was now ready for bigger achievements. The discovery of the neutron answered questions about excess mass in the nucleus. The extra mass was due to neutrons! The alpha particle or helium nucleus (atomic weight = 4) contained 2 protons and 2 neutrons. The lithium nucleus (atomic weight = 7) has 3 protons and 4 neutrons and so on. No electrons in the nucleus were needed.

Thus, the charge on the nucleus (atomic number) is entirely due to protons in it. Its mass (and thus, its atomic weight) is due to the combined mass of the protons and neutrons in the nucleus. Since all atoms, except hydrogen-1 isotope, have an atomic weight at least twice its atomic number, there are at least as many neutrons as there are protons in the nucleus.

What prevents the proton repulsion in the nucleus? Nobody knows for sure. Nuclear scientists have some theories that are beyond the scope of this unit. But we can generalize and say there exists a special "binding energy" in the nucleus. When the protons and neutrons are in the confines of the nucleus they are held together by this binding energy. It must be very strong, but only within the nucleus.

Postscript

The discovery of radioactivity presented a problem: where does the atom get the energy to give off these rays or particles? It was not answered in this chapter. But Albert Einstein gave the key to the answer in 1905 when he presented:

$$E = mc^2$$

(E represents energy, m stands for mass, and c^2 stands for the velocity of light [3×10^{10} centimeters per second or 186,000 miles per second] squared.)

Most people in 1905 and even today do not understand the equation but it tells the story. Matter is energy in a frozen form. What we call energy (heat,electricit,, etc.)

is matter in a fluid form. Putting it another way, matter and energy are equivalent. It is like ice and water which are two forms of the same thing--H_2O. Matter and energy are forms of the same thing. Somehow matter can be converted into energy and vice versa. Confusing? Yes, but that is the story!

In the next chapters we will see how the work of these early pioneers of nuclear science led to a whole new age in society.

CHAPTER VIII. U.S. SCIENCE AND POLITICS MERGE

Letters to the President

On August 2, 1939 Albert Einstein signed a letter addressed to President Roosevelt. It was delivered on October 11, 1939 by Alexander Sachs, a New York financier and informal Presidential adviser (the authors of the letter--several nuclear scientists--used Sachs to convey the letter to Roosevelt because that was the only channel to the President available to them). Einstein, a pacifist, was calling attention to the possible fate of much of the world's population. This letter marked the point at which United States science started to move from the university to national politics. The context of Einstein's letter follows:

Albert Einstein
Old Grove Road
Nassau Point
Peconic, Long Island
August 2nd, 1939

F. D. Roosevelt
President of the United States
White House
Washington, D. C.

Sir:

Some recent work by E. Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in t immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendation.

In the course of the last four months it has been made probable through the work of Joliot in France as well as Fermi and Szilard in America--that it may become possible to set up a nuclear chain reaction in a large mass of uranium, by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable--though much less certain--that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

The United States has only very poor ores of uranium in moderate quantities. There is some good ore in Canada and the former Czechoslovakia, while the most important source of uranium is the Belgian Congo.

In view of this situation you may think it desirable to have some permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence and who could perhaps serve in an inofficial capacity. His task might comprise the following:

a) to approach Government Departments, keep them informed of the further development, and put forward recommendations for Government action, giving particular attention to the problem of securing a supply of uranium ore for the United States;

b) to speed up the experimental work, which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required, through his contacts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the cooperation of industrial laboratories which have the necessary equipment.

I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State, von Weizsacher, is attached to the Kaiser-Wilhelm-Institut in Berlin where some of the American work on uranium is now being repeated.

Yours very truly,
Albert Einstein

(8-1)

According to Sachs, Roosevelt was impressed by the letter but he had other problems to consider. The U.S. was still recovering from a depression and Hitler was taking over portions of Europe (on September 1, 1939 Hitler invaded Poland and World War II began).

But Sachs reminded Roosevelt of Robert Fulton's offer to build steamboats for Napoleon. Fulton thought Napoleon could use them to invade England. Although Napoleon wanted to cross the English Channel for such an invasion, he was not convinced that Fulton could be of service. He considered Fulton to be a dreamer and passed up an opportunity to invade England. Sachs cautioned the President against taking the letter too lightly.

The President listened attentively and carefully reread Einstein's letter. Then President Roosevelt said:

"What you are after is to see that the Nazis don't blow us up."

"Precisely," replied Alexander Sachs.

The President called in his chief military aide and said: "This requires action."

However, Einstein's letter did not result in much action. In November, 1939 a report was submitted which recommended direct government support. It stated:

> The energy released by the splitting of a mass of uranium atoms would develop a great amount of heat. If the chain reaction could be controlled so as to proceed gradually, it might conceivably be used as a continuous source of power in submarines, thus avoiding the use of large storage batteries for underwater power.
>
> If the reaction turned out to be explosive in character it would provide a possible source of bombs with a destructiveness vastly greater than anything now known.
>
> The military and naval applications... must at present be regarded as only possibilities because it has not yet been demonstrated that a chain reaction in a mass of uranium is possible. Nevertheless, in view of the fundamental importance of these uranium reactions

> and their potential military value, we believe that adequate support for a thorough investigation of the subject should be provided.
> We believe that this investigation is worthy of direct financial support by the Government. (8-2)

But no funds were made available. Military men and government officials took a "wait and see" attitude.

On March 7, 1940 Dr. Einstein wrote the President another letter. It was again delivered by Sachs. Einstein wrote:

> Since the outbreak of the war, interest in uranium has intensified in Germany. I have now learned that research there is being carried out in great secrecy and that it has been extended to another of the Kaiser Wilhelm Institute, the Institute of Physics. The Institution has been taken over by the government and a group of physicists under the leadership of C. F. von Weizsacker, who is now working there on uranium in collaboration with the Institute of Chemistry. The former director was sent away on a leave of absence apparently for the duration of the war. (8-3)

This letter had a little more effect than the first. The Army and Navy transfered $6,000 to the study of the utilization of atomic energy. By 1942, a total of $300,000 was spent on this research. It was only later that the U.S. considered this research important. In the period between 1943 and 1945, the U.S. government made about two billion dollars available for this project.

The Gathering Storm

Einstein's letter represents a time in U.S. history when social, political, military, and scientific factors started to come together. Events leading up to World War II started at the close of World War I. The events did not occur in one month but over a period of about twenty years. The events that took place in the 1920's and early 1930's had a great influence on scientists in Europe and the U.S. This was the time of (1) the rise of dictatorships in Europe, (2) the persecution of racial and ethnic groups in Europe, (3) the start of the NAZI drive toward world domination, and (4) the discovery of the fission of uranium nuclei. In a way, all these events influenced and led to the composition of Einstein's letters. We will discuss the first three items together because they are all related.

Conditions in Europe

World War I put an end to the long period of peace in Europe. The time between the Franco-Prussian War (1870) and World War I was one of peace and prosperity in Europe but the First World War marked an end to the security of most of Europe. The war resulted in a weakened social structure, ruined economies, and the decline of empires. The middle class of Europe was attacked from various factions. It was under these unstable conditions that various governments were taken over by dictators.

Rise of Dictators

Between 1918 and 1936, Europe witnessed the toppling of ten governments. They were all taken over by dictators. The first modern dictatorship claimed Russia in January of 1918. The Bolshevik revolution was a prelude of things to come in Europe. The second dictatorship arose in Hungary in March of 1919. The dictator Béla Kun, a disciple of Lenin, remained in power for 133 days. He was replaced by Admiral Nicholas Horthy who soon converted Hungary into a fascist dictatorship.

In October of 1922, Benito Mussolini became the full-fledged dictator of Italy. Military takeover in Spain (1923) was followed by the dictatorship of Josef Pilsudski in Poland (1926). Josef Stalin became the top leader in Russia in 1928 (Lenin died in 1924). The eighth dictator was Antonio de Oliveria Salazar of Portugal. He came to power in 1932--the rule of Portugal has passed from Salazar to a successor within the last year.

It seems unbelievable but Hitler was not the first modern dictator in Europe. He was ninth in a chain of ten dictators before World War II to gain control of a national government (Francisco Franco, who assumed control of Spain in 1936, was the tenth). However, Hitler learned much from his predecessors. His reputation was not derived from the order in which he came to power but what he did when he finally achieved control of Germany. Let's look at the effect the dictators had on European science.

The rise of dictators in Europe had a bad effect on the intellectuals (scholars) within these countries and they experienced varying degrees of restriction. When we speak of intellectuals, we mean all free-thinking people: people who are free and critical thinkers. This includes men of science and other social activities. Although we will only mention scientists, others such as artists, musicians, and playwrights experienced the same oppression.

As Laura Fermi (wife of Enrico Fermi) writes:

> The rise of the dictators did not equally affect intellectuals in all countries, but some general considerations can be made and may help to explain why dictatorial methods were so effective when turned against the intelligentsia [scholars].
>
> Dictators, modern and ancient, dread spiritual and ideological dissent more than open action, for revolt may be easily quashed, but ideas tend to spread insidiously. Hence dictators are especially wary of the behavior of intellectuals and persecute them at the first signs of non-conformity. On the other hand, non-conformity is a trait widespread among intellectuals, who tend to be individualists because they are preoccupied with the product of

> their own minds and trained to be critical of the opinions of others. Organized political opposition to dictators usually springs from intellectual quarters....
>
> The main weapon of modern dictators against the intelligentsia was anti-Semitism. The European intelligentsia was especially vulnerable because a large part of it was Jewish....the proportion of Jews among the intellectuals [was] above that in the rest of the population. In Germany, for instance, the Jews constituted less than 1 per cent (0.9 per cent) of the total population, but among university professors over 12 per cent were Jewish. (8-4)

The intellectuals in Europe were attacked by national governments in many ways. They were deprived of security by officials of law and they lost certain freedoms. But most important, many lost their positions as professors of science or art. Laura Fermi states:

> The oppression of the intelligentsia was facilitated by the fact that in most countries of continental Europe the universities were state institutions. They usually had some autonomy and in questions of learning were governed by the rector and faculty committees. Nevertheless, they were under the central control of the state. All salaries and allocations were paid by the Ministry of Education, and all business was transacted through it; the minister ratified the appointments of professors, changes of policy, constitution of certain faculty boards, and other activities. A similar governmental control was exerted over art academies and music conservatories, and also, though perhaps to a lesser degree, over the theater and the opera. This system worked well under

> democratic governments and constitutional monarchies, relieving the universities and other cultural institutions of much administrative drudgery and the need to raise funds. But it was open to dictatorial abuse. When a dictator arrogated [assumed] all powers of government, he automatically came to hold in his hands the strings that controlled the universities and he could pull them at his whim. (8-5)

Russia

The oppression of intellectuals (in particular Jewish intellectuals) was not conducted in a uniform manner throughout Europe. For example, the class struggle in Russia eliminated the middle class but the Jewish peasant was not directly attacked. Many of these peasants supported the Bolshevik Revolution and were not persecuted. But the middle class intellectuals were oppressed and fled their native land.

This class struggle, which caused an early migration of people, did not last very long. But during this time many contributors to nuclear science left Russia and eventually migrated to the United States. Such men as George Kistiakowsky (former Presidential adviser for Science), George Gamow (theoretical physicist), and Eugene Rabinowitz (radiation-biologist and leader of atomic scientists) came to the U.S. before the mid-thirties.

Hungary

The Béla Kun dictatorship was communist-supported. The so-called Red Tyranny was supported by the workers and many Jewish intellectuals. Admiral Horthy's dictatorship, the Black Tyranny, overthrew the communist government. The victims of Horthy's regime were the supporters of the Reds.

In Hungary, the persecution was aimed primarily at the workers and the Jews. Admiral Horthy's regime became the first modern dictatorship to introduce the racial principle of anti-Semitism. In the past, to be a Jew meant a question of religion. Jews who had converted to other religions were not discriminated against. But under Horthy, this all changed. He declared that the Jews belonged to a separate race and nationality. He purged the public services, and the school and university staffs of all Jews. He introduced the concept of numerus clausus in the universities. Since the population was five percent Jewish, the university enrollment was limited to five percent Jewish students. So almost all the intellectuals migrated to other European countries and later to the United States. The Hungarians, through such scientists as Leo Szilard, Eugene Wigner, Edward Teller, and John Von Neuman, have made great contributions to U.S. science, particularly nuclear science.

Italy

The Italian government under Mussolini was not anti-intellectual or anti-Semitic in general. Only the people who opposed the Fascist Party politics were attacked by Mussolini. In 1931 Mussolini passed a decree requiring all university professors to take a party oath. But he stated in 1933 that he would not pass any anti-Semitic laws. So only a few intellectuals, including some gifted scientists, left Italy for other countries (France, Switzerland, and England mostly). After the Anschluss (unification of Germany and Austria) in 1938, Mussolini became subservient to Hitler and started a racial campaign against Jewish intellectuals. He was on a campaign to Prussianize Italy.

The passing of the first racial laws in Italy coincided with the Munich crisis. Many people fleeing Italy saw that none of the European countries would be secure for them, so if they could afford boat passage, they went to the United States, Latin America, or the Far East. One outstanding nuclear scientist, Enrico Fermi, was in Stockholm, Sweden receiving a Nobel Prize in physics when Mussolini followed Hitler's anti-Semitic lead. Fermi was not Jewish, but his wife, Laura, was. So the Fermi's did not return to Italy. Instead they (Enrico, his wife, and two daughters) went to the United States to live and teach. He was followed by others who were to play important parts in later events.

Germany

Intellectuals who were oppressed in Italy before 1938 were oppressed for political reasons. After 1938 they were oppressed because of their "racial" backgrounds. In Germany, the NAZI laws struck at the intellectuals on political, religious, and racial grounds. It was a simultaneous offensive toward the attainment of Nordic supremacy and the elimination of Jews.

Hitler purged the civil service in April, 1933. Any individual of full Jewish descent, leftist leanings, liberal attitudes, or strongly Republican was removed from office. These new civil service laws applied to universities and many professors and lecturers lost their positions.

The Ministry of Propaganda was organized in 1933. It controlled the intellectual activities outside the university. Many people in the press, arts, and theater lost their jobs. In the spring of 1934 Hitler placed all universities under the control of the Minister of Education. Its first minister, Bernard Rust, had direct control over all the faculties and student bodies. Rules were tightened, civil merit was no longer recognized, and many more university men were dismissed. The whole NAZI attitude can be summed up in a statement by Bernard Rust in 1933. He stated:

> It is less important that a professor make discoveries than that he train assistants and students in the proper views of the world. (8-6)

The jobless scholars migrated to neighboring countries in search of employment but the shadow of NAZI domination over Europe was beginning to grow. In almost all cases the new-found homes of these people were taken over by Hitler and his army. So they migrated to the U.S., England, or to neutral countries. The most famous emigré of Germany was Albert Einstein. There were others (such as Lise Meitner and Otto Frisch, both nuclear physicists), but Einstein was the most prominent.

The Fall of Europe

Many European scientists traveled from country to country seeking security. But they were followed by the NAZI advance. Gradually, Hitler either annexed or conquered neighboring countries causing the climate for intellectuals to worsen. France was their last continental haven. When she fell to the NAZI's, most intellectuals went to England, Canada, Latin America, or the United States. Most of the refugees settled in these countries where they have contributed greatly.

The Atom Gives Up Its Secret

Discovery of Artificial Radioactivity

Besides the discovery of the neutron by Chadwick in

1932, C. D. Anderson found the elusive positive electron (or positron). This find was important because it led to a discovery of greater importance--the discovery of artificial radioactivity.

Irene and Frederic Joliot-Curie had been working with alpha particles for several years. They bombarded various elements with alpha particles in order to cause artificial transmutation. In one experiment they bombarded an aluminum plate with alpha particles. The alpha particles--from a polonium source--struck the aluminum plate and converted the aluminum (mostly aluminum 27 isotope) into phosphorus 30. In the process a neutron was also released. Thus,

$$^{27}_{13}Al + ^{4}_{2}He \longrightarrow ^{30}_{15}P + ^{1}_{0}n$$

(Aluminum 27 plus an alpha particle [or helium nucleus] yields phosphorus 30 and a neutron.)

The Joliot-Curies detected the neutrons and then removed the radioactive source. But the aluminum still gave off some kind of particles. The finding was something new--an element had become radioactive by being struck by alpha particles. Irene and Frederic repeated their experiment and found the same results. Careful investigation revealed that phosphorus 30 was decaying and emitting positrons. The researchers described the second reaction as follows:

$$^{30}_{15}P \longrightarrow {}^{30}_{14}Si + {}^{0}_{1}e$$

(Phosphorus 30 yields silicon 30 and a positron.)

Irene and Frederic made two new isotopes of phosphorus--P-30 and P-32. Both isotopes were radioactive; the radioactivity of phosphorus 30 was half gone in 2½ minutes (half life = 2½ minutes) and phosphorus 32 was half gone in 14.2 days (half life). These experimental findings were extremely important because now man could make radioactive elements. The Joliot-Curies had produced the first man-made radioactive elements.

The Joliot-Curies caused great interest in the production of new radioactive elements. In 1933, artificial radioactivity was unknown, but by 1941, 370 man-made radioactive isotopes had been reported.

The First Atomic Fission

Shortly after Chadwick had identified the neutron, Enrico Fermi (while working in Italy) recognized the possible importance of neutrons for causing transmutations. He figured that it would be easier to bombard a positively-charged nucleus with a neutral particle (the neutron) than with postively-charged particles. So he and his co-workers (Amaldi, d'Agostino, Rasetti, and Emilo Segré) began to investigate what happens when each element in the chemical (periodic) table was bombarded with neutrons.

They started with hydrogen (atomic number = 1), then went to helium (atomic number = 2), and so on. They produced a number of synthetic radioactive isotopes. When they got to the element silver, serendipity entered their experimentation. Someone had put the radioactive source under the table so that it was below the silver sample. Fermi and his workers found that the wooden table did something to the neutrons. The measuring devices indicated that the effect of the neutrons on silver nuclei was greatly increased. The experimenters theorized that the neutrons were slowed down as they passed through the wood. They concluded that slow neutrons were more useful than fast neutrons for bombarding nuclei.

Fermi and his workers continued with their experiments. Now they placed a sheet of paraffin wax between the radioactive source and the same to be bombarded. The paraffin modified (or moderated) the speed of the neutrons (thus the term moderator). The results were better than before. When they reached element 92 (uranium) Fermi started looking for elements beyond uranium. He was hoping to find element 93 (93 protons in the nucleus). As one scientist explains:

> He [Fermi] had observed that each of his radioactives [new isotopes] produced by adding a neutron expelled an electron, so that the atomic number was raised by one and the next higher element in the atomic table was produced. What, he wondered, would happen if he bombarded uranium with neutrons? Uranium was the highest known element in nature--the top of the table. If his previous experience gave any indication, adding a neutron to uranium would cause it to transmute to a new element beyond the border of contemporary knowledge. (8-7)

What Fermi was hoping for is as follows:

$$_{92}U + {}^{1}_{0}n \longrightarrow {}_{93}? + {}^{0}_{-1}e$$

(Uranium isotope plus a neutron yields element 93 plus a beta particle [or electron].)

Fermi considered this to be very possible.

The uranium was bombarded with neutrons for a period of time. Various detection devices monitored the experiment. The uranium sample exhibited an entirely new kind of radioactivity. The usual activity of uranium was present but there were four new types. The four new atoms had radioactive half-lives of 10 seconds, 40 seconds, 13 minutes, and 90 minutes. There appeared to be others but the results were confusing. One of these must be element

93 but which one?

Fermi followed the chemical separation procedures developed by Marie Curie. But he was not familiar with chemical analysis and was not prepared for the results that he observed. Like Columbus he set out to find a goal and thought he had found it.

Fermi decided that element 93 would have chemical properties similar to the element manganese (atomic number = 25). Using the chemicals used for a manganese separation, he isolated the new product from the uranium fraction. Since the new product behaved like manganese, Fermi assumed that he had created element 93 in his laboratory.

However, Fermi and his co-workers were not sure and before they could do more testing the discovery of element 93 was reported. The publicity-hungry Italian government announced the creation of the new element in the spring of 1934. It was now up to other scientists to verify these results.

Several nuclear physicists, aided by chemists, started to repeat Fermi's experiment. By 1935, several research teams had shown that this new radioactivity could be due to a transuranium (beyond uranium) element and the researchers found more than the four activities that Fermi found. The results of their work were very confusing.

Otto Hahn, a German chemist, suggested that all three isotopes of uranium (U-233, U-235, and U-238) had been transmuted by neutrons and were undergoing radioactive decay. He thought that the products were not only element 93, but also elements 94, 95, 96, and 97. What a success! Another German scientist (Ida Noddack) suggested that the uranium atom had split and had formed two lighter elements. However, nobody paid any attention to this suggestion in 1934. Everyone was looking for transuranium elements.

The experiments on this problem pitted a team of German scientists (Otto Hahn, Lise Meitner, and Fritz Strassmann) against a team of French scientists (Irene and Frederic Joliot-Curie and Paul Savitch). Fermi had abandoned the search because he did not have the facilities or background for chemical analysis. Both teams knew that the reward might be a Nobel Prize. Two of the opponents were world-famous woman scientists--Lise Meitner (she fled Germany before the competition ended) and Irene Curie (she was trying to equal her mother's feat of two Nobel Prizes). In 1935, the great race was on.

Just before Lise Metiner went into exile, the German team completed a set of experiments. The results of these elaborate studies indicated that Otto Hahn was correct. The team believed that all the data pointed to transmutation.

The neutron bombardment of uranium had produced four new elements beyond uranium. The evidence pointed to four artificially radioactive elements, elements 93, 94, 95, and 96.

The French scientists completely upset the order by announcing that the new element was not a transuranium element. They reported finding an element similar to lanthanum (atomic number = 57). Imagine, they were looking for element 93 but found element 57 and they had used the chemical techniques developed by Marie Curie. However, the flask they were using contained an impurity. When the French team separated element 57 (it was radioactive) they also found the radioactive impurity. So they diverted their attention to the impurity. They reported the radioactive lanthanum but they were led astray by the impurity. The French thought that this was a new element. Irene Curie and her workers had discovered a clue to "uranium fission," but had not recognized it.

In the summer of 1938 (three years had already passed), Hahn read the Curie-Savitch report and was astonished. "What they found could not be correct," he said. Then he and Strassmann (Meitner was now in exile) set out to track down the elusive element. They were beginning to question their previous results. They bombarded uranium with neutrons. Then Hahn and Strassmann separated the reaction products. They found radioactivity in the test tubes containing barium (element 56), lanthanum, and cerium (element 58) salts. They now concentrated on the activity in the barium fraction.

Hahn and Strassmann suggested that one of the products was an isotope of radium which had chemical properties similar to barium. They made chemical reactions to separate the radium from the barium. They were in for a shock. Radium was not found. Now Hahn and Strassmann did some mental detective work. They played the game twenty questions with their experiment. The sample had to contain barium or radium or both. If the radioactivity was not due to radium (it was found to be absent) then the fraction must be radioactive barium.

Now everything was starting to make sense. Fermi got a positive test for manganese in his sample because radioactive manganese was present. The Joliot-Curies obtained lanthanum because lanthanum was present. The Germans got barium, lanthanum, and cerium because they were all present. The large number of radioactive fractions was the result of the uranium nuclei splitting. The strange behavior of the products was realized. Atoms of element 30 through 60 could be present as products <u>because uranium was splitting into two smaller nuclei</u>. The nuclear scientists were getting elements in the middle of the periodic table and did not know it.

When Hahn and Strassman announced their results, scientists in other countries verified their findings. Meitner (now in Sweden) and Otto Frisch (in Denmark) repeated the experiment and found that uranium did indeed split. In the scientific journal Nature they state:

> It seems therefore possible that the uranium nucleus has only small stability of form, and may, after neutron capture, divide itself into two nuclei of roughly equal size, the precise ratio of sizes depending on finer structural features and perhaps partly on chance. (8-8)

Meitner and Frisch named the new type of nuclear reaction "nuclear fission" because the process resembled the fission of a biological cell.

They found that uranium fission is accompanied by a release of a large amount of energy. Fermi had missed this release of energy in 1934 because of a thin sheet of aluminum. The aluminum, used to absorb low energy gamma radiation, absorbed the nuclear fragments. The high energy fragments were not detected by the measuring instruments.

The existence of atomic energy was first verified as a result of Meitner and Frisch's work. Hahn and Strassmann's work pointed to an atom that could split and release a great amount of energy. The theory of the nuclear reaction was that uranium nuclei split into two lighter nuclei (for example, element 56, barium and element 36, krypton). During the process of fission a certain amount of mass is converted to energy (as described by Einstein's equation, $E = mc^2$). This revelation by the atom sent scientists from around the world rushing back to their laboratories to study the thing they had missed.

Shortly after the discovery of uranium fission scientists found that neutrons were part of the reaction products. This was a very important find. If enough neutrons were released then it was possible to get a fission reaction to sustain itself. Neutrons would not have to be added continually from an external source. All that was needed was some neutrons to start the reaction and then it could sustain itself. It would be like an ordinary fire which keeps burning once it has been started as long as there is fuel available. The only difference is that fission needs nuclei of atoms (uranium in particular). With this finding it appeared as if the use of nuclear energy was around the corner.

The Scientists' Lobby

When Fermi arrived in the United States in 1938 he took a position at Columbia University. He was told about discoveries of the Hahn-Strassmann and Meitner-Frisch teams by Niels Bohr (in January, 1939). Fermi recognized the value of nuclear energy and offered his services to the U.S. Navy.

On March 16, 1939, the day Hitler occupied the rest of Czechoslovakia, Fermi went to Washington to speak to officials of the Navy Department. He carried a letter from Professor George B. Pegram, Dean of Columbia graduate faculties, which informed Admiral S. C. Hooper (Chief of Naval Operations) of Fermi's experiments with atomic energy. The letter stated that the experiments at Columbia University:

> ...might mean the possibility that uranium might be used as an explosive that would liberate a million times more energy per pound as any known explosive.

It also added:

> My own feeling is that the probabilities are against this, but my colleagues and I think that the bare possibility should not be disregarded.... There is no man more competent in the field of nuclear physics than Enrico Fermi. (8-9)

Fermi did not get to see the Admiral. He presented his letter and ideas to two lieutenant commanders. He suggested the possibility of achieving a controllable chain reaction with slow neutrons. This, he implied, could mean atomic power plants for submarines and other naval crafts. He also described the possibility of a chain reaction that might make atomic bombs possible.

The Naval officers were polite to Fermi and listened to his explanations and descriptions. They asked Fermi to keep them informed of further developments. According to a newspaper reporter the officers did not consider Fermi's presentation rational. After Fermi left, one officer expressed the opinion that he (Fermi) was crazy. (8-10)

As months passed, Fermi and other immigrant scientists became concerned about the United States' lack of interest in the utilization of atomic energy. They were more concerned about what the Germans might be doing. These men feared that Hitler would be the first to have atom bombs (if they could be made) and that he would use them to good advantage.

They wanted to alert the U.S. to the potential danger of atomic energy in the hands of the NAZI's. But they had no real way of alerting the government without revealing their ideas to the public. They did not know what the Germans were working on and did not want to give them any ideas.

Finally, they decided to take action and personally inform President Roosevelt about the situation. A delegation of foreign scientists (called the Fermi Five)--Leo Szilard, Eugene Wigner, Edward Teller, Victor F. Weisskopf, and Enrico Fermi--called upon Albert Einstein for his assistance.

They wanted Einstein to see the President of the United States. But Einstein refused because he did not know the President personally. They tried to persuade him but he refused to go. So they compromised. The scientists composed a letter to President Roosevelt and Einstein signed it. This letter became Roosevelt's introduction to atomic energy.

In the next chapter, we will consider the race which the United States reluctantly entered. We will look at some aspects of the development of the atom bomb.

CHAPTER IX. FROM THE LABORATORY TO ALAMOGORDO

The Atomic Age Begins

On July 16, 1945 a woman drove into a small town in New Mexico. From a distance of sixty miles she had just seen a man-made fragment of a star; she had just seen the first atomic explosion. It was about 5:30 a.m. and the woman began knocking on doors to tell people what she had seen. She shouted:

> You must listen--it's incredible.
> I've just seen the sun rise--and
> then set again a moment later!
> (9-1)

This was the introduction of atomic energy to people in this part of the world. These unsuspecting witnesses were astonished, but so were the two hundred official observers.

The leaders of the United States' atomic bomb project stood at observation posts ten and twenty miles from "Zero" (code name for the exact test site). Trinity (code name for the bomb) was on a tower and ready for the test. The observers, who were in concrete shelter houses, were waiting for the proof of four years of speculation and hard work. They were there to determine if a certain minimum mass of material could produce an atomic explosion. They were testing the results of a two billion dollar gamble made by the United States government.

Although these men--military, scientific, governmental, and industrial officials--were prepared for a dud (failure to explode) or a great explosion, they were not prepared for what they saw. A newspaper reporter (William L. Laurence--official Manhattan Project reporter) wrote after the war:

> Suddenly, at 5:29:50, as we stood huddled around our radio, we heard a voice ringing through the darkness, sounding as though it had come from above the clouds: "Zero minus ten seconds!" A green flare flashed out through the clouds, descended slowly, opened, grew dim, and vanished into the darkness.
>
> The voice from the clouds boomed out again: "Zero minus three seconds!" Another green flare came down. Silence reigned over the desert. We kept moving in small groups in the direction of Zero. From the east came the first faint signs of dawn.
>
> And just at that instant there rose as if from the bowels of the earth a light not of this world, the light of many suns in one. It was a sunrise such as the world had never seen, a great green supersun climbing in a fraction of a second to a height of more than eight thousand feet, rising ever higher until it touched the clouds, lighting up earth and sky all around with a dazzling luminosity.
>
> Up it went, a great ball of fire about a mile in diameter, changing colors as it kept shooting upward, from deep purple to orange, expanding, growing bigger,

rising as it expanded, an elemental force freed from its bonds after being chained for billions of years. For a fleeting instant the color was unearthly green, such as one sees only in the corona of the sun during a total eclipse.

On that moment hung eternity. Time stood still. Space contracted to a pin point. It was as though the earth had opened and the skies had split. One felt as though he had been privileged to witness the Birth of the World.

A huge cloud rose from the ground and followed the trail of the great sun. At first it was a giant column which soon took the shape of a supramundane mushroom. Up it went, higher and higher, quivering convulsively, a giant mountain born in a few seconds instead of millions of years. It touched the multicolored clouds, pushed its summit through them, and kept rising until it reach a height of 41,000 feet, 12,000 feet higher than the earth's highest mountain.

All through the very short but long-seeming time interval not a sound was heard. I could see the silhouettes of human forms motionless in little groups, like desert plants in the dark. The newborn mountain in the distance, a giant among the pygmies of the Sierra Oscuro range, stood leaning at an angle against the clouds, like a vibrant volcano spouting fire to the sky.

Then out of the great silence came a mighty thunder. For a brief interval the phenomena we had seen as light repeated themselves in terms of sound. It was the blast from thousands of blockbusters going off simultaneously at one spot. The thunder reverberated all through the desert, bounced back and forth from the Sierra Oscuro, echo upon echo. The ground trembled under our feet as in an earthquake. A wave of hot wind was felt by many of us just before the blast and

> warned us of its coming.
> The big boom came about a hundred seconds after the great flash--the first cry of a newborn world. (9-2)

The test was a success--the atomic fission bomb worked. The atomic flash and thunder in New Mexico gave the answer to the question: "Will it work?" Scientists, military men, and government officials had asked this question for over four years. And the answer was, YES. Four years of hard work had been rewarded by a successful test.

The route to this test was not an easy one. People from different occupations had to cooperate in this venture. The scientist had to leave his university haven and work with military men and engineers. The government and government officials had to support a project without any guarantee that it would succeed. This project was the biggest venture ever taken by one country. It required thousands of people to construct and operate the project facilities.

What was the main goal? Beat Hitler to this weapon. It was a race between Germany and the Allies (U.S., Canada, Britain, and France). What was the possible prize? Freedom. The leaders felt that if Hitler gained possession of this weapon he would be in a position to fulfill his dream--world domination. Let's go back and look at some of the activities that led to "Zero" or as one scientist called it, "The Day of Trinity."

The United States and Its Quest

The year 1940 dragged at a slow pace for Fermi and his small group of exiles. They kept receiving disturbing reports from their colleagues abroad. The number of people (scientists and engineers) joining the uranium fission project of Kaiser Wilhelm Institute in Berlin was increasing. Norway was invaded by the Germans and they gained control of the Norsk Hydro hydrogen electrolysis plant. This plant was the largest producer of heavy water (water that consists of the heavier hydrogen isotope, deuterium) in the world. In 1939, German scientists had publicly stated that the manufacture of heavy water might become very important to their war effort. So, as the scientists studied the scarce and sketchy information, they concluded that the Germans were working toward an atomic fission bomb.

Early Activities

Nuclear research in 1940 and 1941 continued under the National Defense Research Committee (NDRC), established by President Roosevelt in June, 1940, but it was on a relatively small scale in university laboratories. However, several important facts were uncovered. Fermi and Szilard, at Columbia University, showed that carbon, in the form of very pure graphite, could be used as a moderator (instead of heavy water). They figured that they would need tons of graphite. In 1940, working with the giant University of California cyclotron, a team of university scientists produced element 94 (plutonium). Glenn Seaborg (present chairman of the Atomic Energy Commission, AEC), and Edwin McMillan, under the direction of Emilo Segré (Italian immigrant) showed that uranium 238 could be transmuted by neutron bombardment into a new element, plutonium 239 (atomic number 94). They succeeded in isolating a tiny quantity of plutonium, and found that it underwent fission when bombarded with slow neutrons. This discovery was very important; if one could establish a chain reaction then uranium 238 could be converted to plutonium 239.

The idea was simple; put natural uranium (a mixture of U-235 and U-238) into a reactor and if possible start the chain reaction. The U-235 would be consumed by fission and would produce energy and free neutrons. Some of the free neutrons would smash into uranium 238 nuclei which would eventually become plutonium 239. The process would be as follows:

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow \text{Fission products} + {}^{1}_{0}\mathrm{n}$$

$$^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{239}_{92}\mathrm{U}$$

$$^{239}_{92}\mathrm{U} \longrightarrow {}^{238}_{93}\mathrm{Np} + {}^{0}_{-1}\mathrm{e} \longrightarrow {}^{239}_{94}\mathrm{Pu} + {}^{0}_{-1}\mathrm{e}$$

This new element (plutonium 239) was important because it could be used for a role similar to uranium 235.

In 1941, Robert Oppenheimer at the University of California determined what is known as the "critical mass" of uranium 235 (he was verifying Chadwick's 1940 calculations). He found that uranium 235 had a critical mass somewhere between 22 and 66 pounds--the correct value is 35 pounds. In addition, Oppenheimer showed that the critical mass of plutonium was 16 pounds.

This meant that if 35 pounds of U-235 (or 16 pounds of plutonium 239) is placed in contact with a neutron, it could undergo a self-sustaining reaction (a chain reaction). The scientists did not know if they would get an explosion or a chain reaction. Thus, the results could be a bubbling mass of uranium (or plutonium) metal or a violent explosion. This was the big question: "What would they get?" As William Laurence states:

> They fully realized that the very heart of the atomic problem was to obtain definite experimental proof that a chain reaction which would light an atomic fire, or explode an atomic bomb, would defintely take place, provided a sufficient quantity of the fissionable element, U-235, could be concentrated. But here was the grim joke nature had played. She had mixed up its only fissionable element with an atomic-fire extinguisher, U-238, that would not permit an atomic fire (chain reaction) ever to get started, while at the same time she made it impossible to separate the fissionable element (U-235) from the atomic-fire extinguisher.
>
> A self-sustaining chain reaction, their theories strongly indicated, would, when properly controlled, yield tremendous amounts of atomic power for industry, while a chain reaction allowed to go uncontrolled would yield an explosive force millions of times greater than TNT. <u>A controlled chain reaction would be like the controlled burning of gasoline in an automobile engine. An uncontrolled chain reaction would be like the dropping of a lighted match in the gasoline tank.</u> [My italics]
>
> Definite proof that a chain reaction was possible would mean, they knew, that we would have to go all out to develop an atomic bomb, since the chances would then be great that the Germans already had a head start on us and might be on the verge of producing the weapon.
>
> On the other hand, should experiment reveal some unknown factor that would make a chain reaction impossible, we would then have definite proof that it would be impossible for the Germans to produce an atomic bomb. (9-3)

The important factor was time. Would the Allies get the answer to the big question in enough time to do something about it?

The British Contribution

When Britain entered the war, her scientists were called into service. Their main goal was the perfection of radar and their time was spent with this project. However, three German refugees (Francis Simon, Rudolf Peierls, and Otto Frisch) had more leisure time than most British scientists. They were not involved in radar research and so they had time to think about the remote chances of an atomic bomb. When they concluded that it was a possibility, they asked M. L. Oliphant to convey their opinion to the U. S. officials.

In the autumn of 1941, M. L. Oliphant, an Australian member of the British scientific team, visited the United States. He contacted government officials and explained Britain's problem. British intelligence reported that the Germans were working toward a chain reaction. The risk that Britain would be attacked by radioactive poisons or atomic bombs increased daily.

However, the British could not do anything about it. The war was already occupying most of their scientific research. Oliphant explained that the British could not carry out any more major projects, but he felt that the United States could undertake this project (the U.S. was not at war at this time). Oliphant felt that the U.S. had the technical potential to carry out this scientific and industrial program. Advice from this outsider carried much weight and was a major factor in the decision that U.S. officials took in 1941. Oliphant had done an important service. As Dr. Szilard said to a Congressional hearing in 1945:

> If Congress knew the true history of the atomic-energy project, I have no doubt but that it would create a special medal to be given to meddling foreigners for distinguished services, and Dr. Oliphant would be the first to receive one. (9-4)

The British showed us that an atom bomb was a definite possibility. This meant that we had given the NAZI's a three year head start. So on December 6, 1941 (the day before the Japanese attacked Pearl Harbor) the United States decided to go to work on the project. This was a monumental day in the United States. Our scientists became involved with social and political as well as scientific problems.

Although the U.S. decided to go into research and development of atomic weapons in 1941, it wasn't until 1943 that most work started. Most of 1942 was spent organizing the project. The actual building of our huge plants for producing fissionable materials started in the spring of 1943. The early leaders in this work were the foreign scientists. As one project reporter states:

> American-born nuclear physicists were so unaccustomed [my italics] to the idea of using their science for military purposes that they hardly realized what needed to be done. Consequently the early efforts both at restricting publication (of atomic developments) and at getting government support were stimulated largely by a small group of foreign-born physicists, centering on Leo Szilard and including Eugene Wigner, Edward Teller, Victor F. Weisskopf, and Enrico Fermi. (9-5)

The Manhattan Project

During the summer of 1941, President Roosevelt had organized the Office of Scientific Research and Development (OSRD). This agency, under the direction of Vannevar Bush (computer inventor and President of Carnegie Institute), started to mobilize civilian scientific research. James B. Conant (chemist, educator, and later President of Harvard) headed the National Defense Research Council which was in charge of military programs. These two U.S. scientists were the two civilians chiefly responsible for the atomic bomb program.

The entry of the United States in World War II increased the desire to proceed with the atomic project. On

December 15, 1941 Roosevelt appointed a Top Policy Group to handle political policy related to the atomic bomb project. The group consisted of Roosevelt, H. A. Wallace (Vice-President of the United States), H. L. Stimson (Secretary of War), G. C. Marshall (Chief of Staff), V. Bush (Director of OSRD), and J. B. Conant (Director of NDRC). They decided that OSRD should press for immediate planning (engineering and scientific) for this project. Construction of pilot plants was given highest priority. At this meeting Dr. Bush recommended that the Army take over the atom bomb project when full-scale construction began. He also requested that a competent Army officer be assigned to head the project.

In August, 1942 everything pointed toward full-scale production of materials, but pilot plants were not built. The United States was gambling on the knowledge of her nuclear scientists. At this time the atom bomb project was put under the Army Corp of Engineers. The new branch of the engineers was known officially as the Manhattan Engineering District (generally it was called the "Manhattan Project").

In September, 1942 Major General Leslie R. Groves was put in charge of the Manhattan Project. He took over the control of scientific research and development as well as production. General Groves was an excellent administrator who had to pull together industrialists, military men, and scientists. He was responsible for the cooperation of these diverse groups. In the beginning, a number of practical engineers on the project considered the university scientists to be longhairs and crackpots. This led to friction which was brought to Grove's attention. Groves, a very able engineer, called a meeting of all top engineers on the project and delivered this short speech:

> Listen, it has taken a lot of touble to bring all these screwballs together and to get them to work for us. Now you work with them. (9-6)

That ended the meeting and much of the friction.

Secrecy

When the foreign scientists first started lobbying the U.S. Government for research support they agreed upon voluntary secrecy. All scientists outside of Germany agreed not to publish any findings related to atomic fission. When the Army took over, they strengthened the secrecy regulations on the project (they went to the point of hiring illiterate guards to handle the burning of the paper in the wastebaskets). All reference works pertaining to uranium were classified as secret and removed from library shelves. An example of this military order was the removal of the September 7, 1940 issue of the Saturday Evening Post. It contained an article by William Laurence entitled, "The Atom Gives Up." It gives a good account of the discovery of fission and work on uranium and it is still worth reading today.

Another precaution was the assigning of bodyguards to all the top scientists. In addition, the top scientists were given assumed names. Thus, Enrico Fermi became Henry Farmer; Eugene Wigner became Wagner; and Niels Bohr became Nicholas Baker (or Uncle "Nick"). This may have fooled the Germans but it also confused the scientists. One day, Wigner was challenged by a guard. Wigner said his name was "Wigner," then changed it to "Wagner." The guard asked Fermi (who was with Wigner) if his friend's name was "Wagner." Fermi replied, "Just as surely as my name is Farmer." The guard let them pass. Arthur Compton had two aliases; one for the west (Mr. Comas) and one for the east (Mr. Comstock). Once he fell asleep on an east-west flight. When the stewardess awakened him for identification he asked "Where are we?" Luckily, his bodyguard presented the ticket for Mr. Comas before Compton could make a mistake.

Employment

The Manhattan Project required an army of workers. People were needed for construction of plant facilities and they were needed for the operation of these facilities. But the workers were hired by a regular industrial firm and did not know who their employer really was. The Army was interested in people with special skills but they did not advertise for them specifically. For example, one woman physicist answered a general ad for employment. She had to fill out certain forms for application. One form asked for her husband's occupation or trade. She wrote down "lead engraver." Well, she did not get a job that day but when she returned to her home she found that her husband had been hired by the company. The interviewers read her application and rushed out to hire her husband, a specialist with lead plates.

This was the project that General Groves administered. Its principle facilities were at Chicago; Oak Ridge, Tennessee; Hanford, Washington; and Los Alamos, New Mexico. We'll look at these separately to see how the Manhattan Project was a coordinated operation of people from various walks of life. The research which began with Becquerel's experiment had been taken from the universities and concentrated in these four centers.

First Chicago Pile

In 1940, Fermi took the $6,000 given to Columbia University (awarded by the U.S. Army and Navy) and bought a large amount of graphite. He also obtained uranium oxide (pure uranium was not available in large quantities) and started to build an atomic pile. It was called a pile because it consisted of a stack of bricks made of graphite. The black graphite dust made Fermi's "bricklayers" look like coal miners. Their wives wondered what they were doing but the scientists did not tell them; they were sworn to secrecy.

The pile was built of layers of graphite bricks (used as a moderator). Cube-shaped cans filled with uranium (fissionable material) oxide were placed among the graphite. Fermi wanted to build a block four feet on a side and ten feet high. But he found that the ceiling was too low.

So Fermi went to Dean Pegram and explained that he needed a bigger room. Dr. Pegram looked around the Columbia campus and found a chapel-like room in Schermerhorn Hall. The construction of the pile was shifted to new facilities. However, the building project was slow because Fermi did not have enough help. As he told it:

> Well, there we started to construct this structure that at that time looked

> again in the order of magnitude larger than anything we had seen before....It was a structure of graphite bricks, and spread through these graphite bricks in some sort of pattern were big cans, cubic cans, containing uranium oxide.
>
> Now, as you know, graphite is a black substance. So is uranium oxide. And to handle many tons of both makes people very black. In fact, it requires even strong people. Well, we were reasonably strong, but we were, after all, thinkers.
>
> So, Dean Pegram again looked around and said, 'Well, that seems to be a job a little beyond your feeble strength; but there is a football team at Columbia that contains a dozen or so of very husky boys who take jobs by the hour just to carry them through college. Why don't you hire them?'
>
> And it was a marvelous idea. It was really a pleasure for once to direct the work of these husky boys, canning uranium--just shoveling it in--handling packs of fifty or a hundred pounds with the same ease another person would have handled three or four pounds. And as they were passing these cans, fumes of all sorts of colors, mostly black, would go in the air. (9-7)

In early 1942, Professor Arthur H. Compton who was made director of the chain reaction project (called the "Metallurgical Laboratory"), moved Fermi, his fellow scientists, and tons of graphite and uranium oxide to Chicago. At the University of Chicago campus, the entire graphite-uranium contraption was reassembled. Construction of CP-1 (Chicago Pile One) was begun early in November, 1942.

The pile was reassembled under the west stands of Chicago's Stagg Field. Holes were drilled into the graphite blocks into which slugs of uranium oxide or uranium metal were placed. Alternate layers of graphite contained these slugs. The other layers consisted of solid blocks of graphite.

This great pile of graphite bricks pocked with uranium oxide or uranium pellets was built in the shape of a sphere. A wooden scaffold was built to support the sphere. Six tons (12,000 pounds) of uranium metal and fifty tons (100,000 pounds) of uranium oxide were embedded in 51 layers of graphite (four hundred tons). It took all of November, 1942 to build the pile. On December 2, 1942 the pile was ready for testing.

The crucial experiment was performed that same day, December 2. 1942. On that day, scientists verified their theory. A chain reaction was possible. Atoms of uranium split and released neutrons which caused other uranium atoms to split. These atoms released neutrons which split other atoms, and so on. The results meant that a self-sustaining chain reaction was possible. This pile contained the first man-made fire that was not due to fossil fuels. It was the first controlled nuclear reaction.

However, the scientists did not know that once the reaction was started it could be kept under control. So they used all the devices known to science to control the reaction. They used control rods of boron and cadmium which are excellent neutron absorbers. One scientist stood ready with a fireman's axe to cut the rope and release the control rods. As an added precaution, there were two young scientists standing on a platform above the pile. They had large bottles of cadmium salt solution. They were to kick the bottles off the platform if signaled to do so (they were known as the "suicide brigade"). These men stood for two hours waiting for the signal. But it was not necessary; the first reaction did not start a new "Chicago fire."

The historic event is recounted by the official reporter, William Laurence, who wrote:

> The great moment came when Fermi ordered his assistant, George Weil, to pull out the last control rod "another foot." All the other control rods had been pulled out previously.
>
> "This is going to do it," Fermi told Dr. Compton, who was standing beside him on the balcony overlooking the furnace.
>
> Four tense minutes passed. The neutron counters began to click louder and louder, faster and faster. Fermi, who was doing fast calculations on a slide rule as his eyes darted from one dial on the instruments to another, suddenly closed the rule with a click that could not be heard amidst the

> racket of the neutrons in the instruments. He looked calm, detached, a captain bringing his ship into port.
>
> It was three-twenty-five in the afternoon in Chicago. The moving pencil that recorded what was going on inside the atomic furnace moved upward and up, upward and up, in a straight vertical line that did not level off as it had done before. This meant that a chain reaction was taking place inside the structure. The first atomic fire had been lighted.
>
> "The reaction is self-sustaining," Fermi said amidst the violent clicking of the neutron counters. His face, tense and tired, broke into a broad smile.
>
> For twenty-eight minutes the atomic fire was allowed to burn. Then Fermi gave the signal and it was stopped abruptly. Man had released the energy of the atom's nucleus and had also proved that he could control it at will....

Laurence continues:

> When the fire was extinguished, Dr. Wigner, with the flourish of a magician, pulled a bottle of Chianti out of an imaginary hat. All drank a silent toast out of paper cups.
>
> And as they all filed out of the heavily guarded gate much earlier than usual, a puzzled guard asked, "Say, Doc, anything happen in there?" (9-8)

Yes! Something did happen in there, but it was kept a secret from the world until the bomb was dropped on Hiroshima.

The Production of Materials

Hanford, Washington

As the chain reaction experiment was going on, a conference was being held in another building at the University of Chicago. The discussion was whether to begin the construction of the gigantic plutonium plants. The cost of such plants was estimated to be about four hundred million dollars. However, the success of this operation was dependent upon a chain reaction. Top DuPont engineers (asked by the government to supervise the design and construction of the plant) were arguing the merits of the project. They did not want to build a plant without being sure that a chain reaction was possible.

As the experiment neared its climax, Dr. Compton invited Dr. C. H. Greenwalt (member of DuPont's board of directors) to come with him. On the way to the squash courts, Compton explained the experiment taking place. When they arrived at the court, the chain reaction was already underway. Dr. Greenwalt (now sworn to secrecy) rushed back to Eckhart Hall. With his eyes about to pop out of his head he said:

> Gentlemen, there is no need for further discussion. (9-9)

These words were the go ahead for the Hanford, Washington, plant which was the main plutonium 239 producing facility. DuPont supervised the construction and operation of this chemical engineering project under a contract with the government. The contract with the government awarded DuPont a total profit of one dollar.

Oak Ridge, Tennessee

The Oak Ridge facilities arose out of nowhere into a city (population about 30,000) and a huge industrial complex. The work was done by the Stone and Webster Engineering Corporation and the Tennessee Eastman Corporation which included the construction of a medium-sized uranium pile. This pile supplied information about the extraction of used uranium slugs and the separation of plutonium from these slugs. Another service performed by the plant was research on the biological effects of radiation. A large laboratory was set up for chemical analysis, for research on purification, and facilities for medical research.

The medical research resulted in some important safety practices. Workers were required to carry small devices for detecting radiation. The air of the rooms was tested by a device called "Sneezy," while desks and drawers were monitored by "Pluto" who could sniff out radiation. All exits were equipped with radiation detecting devices which sounded an alarm when and if someone was leaving the plant with radioactive contamination on their body or clothing.

Elsewhere at Oak Ridge, huge factories for isotope separation were being built. One was an electromagnetic process. Ernest D. Lawrence (he won the Nobel Prize for inventing the cyclotron) modified his atom smasher into a magnetic "race-track." He reasoned that since U-235 was lighter than U-238, a magnetic field would cause moving U-235 isotopes to follow a smaller circular path. Thus, if two isotopes were whirled around in a "race-track" they would separate. Then with a special collector the beam of U-235 isotopes could be collected. The Y-12 plant, a huge magnetic "race-track," was built for the separation of the uranium isotopes. This plant required enough steel to build a fair-sized fleet of ships. In addition, silver wire (copper wire was not available) had to be used around the large magnets. This required the use of a large fraction of the silver reserves of the Federal Bank of the United States (about 15,000 tons of pure silver--worth about a half billion dollars).

Probably the best known plant at Oak Ridge was and is building K-25. This is the <u>gaseous diffusion</u> factory. It is a building about two miles in circumference. The plumbing in the building required enough pipe to stretch from Chicago to St. Louis and back (about 600 miles round trip).

Building K-25 is used to separate U-235 from U-238. The principle behind the method is fairly simple. A mixture of gases is pumped through a porous membrane (a sheet of some material with tiny holes). The lighter gas passes through the membrane a little more easily than heavier gases. When the gases pass through a large number of membranes the gases are separated more and more. If several thousand of these porous barriers are used, the lighter gas is almost completely separated from the heavier gases. K-25 contained a system for pumping gases and thousands of porous barriers.

In the case of uranium, it is converted into uranium hexafluoride gas (UF_6). The uranium 235 hexafluoride gas is lighter than uranium 238 hexafluoride. So the two gases could be separated if you have a suitable barrier and a large building. Construction of the large building was easy. Its construction was begun before the barrier problem was solved. Making a useful membrane was the big headache.

Harold C. Urey (Nobel Prize winner for his discovery of deuterium) and Percival C. Keith (vice-president of an engineering company) were the supervisors of the membrane project. They had a very important problem to solve. They had to make thousands of barriers that would resist corrosion and withstand high pressures. Each barrier had to have billions of invisible holes and the had to be clog-proof. It appeared to be an impossible task. But the barrier problem was solved during mid-1944 (K-25 was already built).

The spirit in these plants was very unusual. Ordinary people operated the plants. Everyone there felt that they were taking part in an important project but they did not know any more than that. Tennessee girls were employed to supervise the electromagnetic process. After a brief training period these girls did a better job operating this plant than the scientists who designed it. The u-shaped gaseous diffusion plant was so large that workers rode on bicycles from one control point to another.

These workers were living in an unreal world. They were working in huge plants which consumed large quantities of raw materials but the people never saw any products. All they ever saw were long processions of trucks delivering their loads. The official reporter asked them what they were making in the plants, Some replies were:

I'm making a dollar thirty-five an hour.

> I'll bet that whatever they're making here, they could get it much cheaper if they went out and bought it.
>
> ...front ends of horses to be shipped to Washington for assembley (the stock joke at Oak Ridge). (9-10)

Los Alamos, New Mexico

By early 1945, the last of the reactors at Hanford was put into operation. Plutonium was separated in the adjacent chemical plants. At Oak Ridge, enriched U-235 production had begun. The concern for lack of fissionable material disappeared. The only problem was the bomb itself.

As soon as some U-235 or Pu-239 was produced it was rushed by special courier to Los Alamos. This is where the atom bomb was being designed.

Los Alamos is situated on an isolated plateau in the heart of New Mexico. The site was a voluntary concentration camp for scientists and their families. It was the home of most of these people until about six months after World War II.

The operation at Los Alamos was directed by Robert Oppenheimer. He was a young theoretical physicist who assembled a galaxy of mathematicians, physicists, and metallurgical and balistic experts. Their objective was simple: develop the actual mechanism of the bomb. But the theoretical and practical aspects (many parts still secret) presented them with many difficult problems.

The idea was simple: bring sub-critical masses together to form a critical mass. But these pieces had to be combined in a very short period of time (less than one millionth of a second). The simplest system consisted of uniting two sub-critical masses in a tube like an ordinary gun barrel. One of the pieces was shot (using regular explosives) into the second piece which was situated at the other end of the tube. Now this produced a critical mass and a chain reaction should occur. Everyone was confident that the "good old gun" would work. Six-foot long barrels had already been made and tested in New Mexico.

This was the planned method for uranium 235, but plutonium 239 was more difficult. As Pu-239 is produced in a pile it is partially transmuted to Pu-240. This Pu-240 splits by spontaneous fission (splits without being struck by neutrons) and releases neutrons. These free neutrons increase the chance of a premature explosion. So a more complex solution was necessary.

An implosion method was designed for this bomb. A hollow sphere of Pu-239 was surrounded by explosive charges. According to theory, the exploded charges would cause the hollow Pu-239 sphere to collapse. In the process, the sub-critical sphere would be reduced to a solid sphere. This sphere would be greater than the critical mass and a chain reaction should occur. This device had a neutron source at its center and was encased in a thick steel jacket. This was only a theory--it still had to be tested.

Besides the above problem, Oppenheimer's team was faced with a weight problem. These bombs were to be carried by B-29 Super-Fortresses (our biggest bombers in 1945), so they had to make the bombs lighter by making them more efficient. The bomb mechanism problems were solved by April, 1945. But enough fissionable material was not produced until the beginning of July.

Finally, in July of 1945, two bomb models were prepared. Each had an explosive power equal to 20,000 tons of TNT. The "Little Boy" which used U-235 was ten feet long and two feet wide. It was equipped with the gun-barrel type mechanism and weighed about four tons. "Fat Boy," which used Pu-239, was about ten feet long and four feet wide. This monster weighed nearly five tons and was equipped with an implosion mechanism.

Since the implosion method had not been tried, the first test bomb (Trinity) was a plutonium 239 device. As the day of the test approached, the scientists were subject to feelings of doubt. During this time someone wrote a poem which reflected their feelings. Called the "Los Alamos Blues," it goes as follows:

> From this crude lab that spawned the dud
> Their necks to Truman's axe uncurled
> Lo the embattled savants stood
> And fired the flop heard round the world
> (9-11)

Of course, we already know the results. But what about the Germans? We'll consider them in the next chapter.

CHAPTER X. SCIENCE WINS THE WAR

The Alsos Mission

United States scientists knew very little about the German "uranium problem." Intelligence reports were very sketchy and often contradictory. As the Allies prepared for the invasion of France, rumors about a German secret weapon were spread. Then the German propaganda machine also started mentioning a "new secret weapon." Allied scientists assumed that the NAZI's were talking about atomic weapons.

Our assumption from the beginning was that German science was ahead of us. When the Fermi Five approached Einstein, they believed that Germany had already begun work on the uranium problem. In December, 1942 the first chain reaction was achieved and the production of an atom bomb became a real possibility. This event strengthened our fears of the NAZI's success. After all, Otto Hahn had discovered uranium fission and the first papers on a chain reaction were of German origin. Everyone, including the Germans, knew that German science was superior to United States science.

The reasoning of U.S. scientists was simple logic.

Many of them had been trained (at least in part) at German universities. They had a natural and justifiable admiration for German science. They thought that since the Germans had started uranium research about two years before the U.S. they must be at least two years ahead of us. We assumed that the Germans had been operating chain reaction piles for several years.

If Germany had nuclear piles (or reactors) they could make atom bombs or radioactive dust.

The nuclear scientists were convinced that Hitler had radioactive dust that would be sprinkled on cities. The fear was so real that the scientists were even sure of the time and place of Hitler's first attack. They figured that Hitler would attack Chicago (the heart of early nuclear research) with radioactive materials on Christmas Day (1942). Some members of the Chicago research team sent their families out of town for the holiday. It was rumored that instruments to detect radioactivity were set up around Chicago at that time, but this was never confirmed.

The Allies (U.S. and Britain in particular) knew that the Germans were very interested in the Norwegian (Nordsk-Hydro) hydro-electric plant. The Germans--we assumed correctly--wanted to use the heavy water produced by this plant as a moderator for an atomic pile (or reactor). After the Germans conquered Norway, the production of heavy water was increased and the water was shipped to Germany. So Britain and the U.S. sent two commando missions (November, 1943 - February, 1943), an airplane bombing mission (November, 1943), and a sabotage mission (January, 1944) to Norway to destroy the hydro-electric plant and the heavy water.

Of course, the Germans thought we attacked their heavy water source because they were ahead. Why else would we want to delay uranium research? The Germans rebuilt this hydro-electric plant faster than we expected. So they confirmed our suspicions; the uranium project had a high priority in the German war effort.

Ordinary intelligence information was of little value. The OSS (Office of Strategic Service--forerunner to the CIA) reported rumors about secret weapons and atom bombs, but their information did not make sense. The men of OSS were not nuclear scientists and could not determine what was scientifically important. What we needed, as one scientist explained, was a Mata Hari with a Ph.D. in physics.

So, General Groves set up a special mission to investigate the achievements of the German nuclear scientists. The "Alsos Mission" (<u>alsos</u> is the Greek word for <u>groves</u>), which was headed by Colonel Boris T. Pash, consisted of scientists and military men. The key scientist was

Professor Samuel A. Goudsmit, a Dutch refugee who taught at the University of Michigan before the war (later, he was Director of the Brookhaven National Laboratories). Goudsmit was selected for this job because he had the perfect background. As he states:

> (1) Although my field was atomic physics, I was not working on the atom bomb project; in other words I was expendable and if I fell into the hands of the Germans they could not hope to get any major bomb secrets out of me.

and

> (2) I was personally acquainted with many of the European scientists, knew their specialties, and spoke their language. (10-1)

The Alsos Mission was to find out all they could about German scientific work. Their main objective was to assess the progress of the nuclear scientists and stop the German research. This military-scientific mission was a team effort. It was the first military-scientific intelligence mission in U.S. history. The military men (under Pash) were responsible for getting the scientists to see people and places. The scientists (under Goudsmit) had to interview German scientists and carefully examine all their scientific papers and laboratories. The mission has been described as "one of the finest examples of cooperation of scientists and the armed forces."

The Alsos Mission arrived in Paris after the very first

Allied troops occupied the city (August, 1944). The information they received was sketchy and disappointing. Pash and Goudsmit received information about fires and explosions related to nuclear research but they could not get anything worth mentioning. However, they had one real scare. They learned that a train load of thorium ore had been transfered from France to Germany. Pash and Goudsmit were sure that the Germans were using the thorium. Further investigation revealed that the thorium had been shipped to a toothpaste company. One German scientist, employed by the toothpaste company, wanted to use the thorium in toothpaste. This was his answer to chlorophyll, fluorides, etc.

The first real breakthrough for Alsos came after the occupation of Strasbourg in November, 1944. The Alsos Mission found papers that gave the names and addresses of all leading German scientists and the locations of their laboratories. From this point on, the pursuit of German scientists was relentless. Alsos military personnel would often filter through German lines ahead of the advancing Allied armies to capture bewildered German scientists with all their equipment and scientific data. These scientists were taken prisoner and brought back behind Allied lines.

One by one, the leading German scientists were taken prisoner by this unorthodox manner and thoroughly questioned. Gradually, Goudsmit and his fellow scientists pieced the story together. By early 1945, the picture was complete and the truth about the German's atomic research was revealed. Goudsmit and the Alsos Mission had raised the curtain of secrecy about the German atomic bomb program. With the secrecy removed, Allied officials realized that they were competing with a German atomic bomb myth. They were racing against German science as they had known it before World War II. They did not realize that this science had changed. Every clue about Germany's nuclear research handed to the Allies was analyzed in favor of German science. Letters and intelligence reports about failures were assumed to be false information to confuse us. The feared German atomic and radioactive dust bombs were nonexistent. Let's look at some events that took place in Germany.

The German Effort - Reasons for Failure

Early in 1939 (about three months before Einstein's letter to Roosevelt), several German physicists called attention to the future prospects of nuclear weapons. They informed military and other authorities about the possibility of making a superexplosive as a result of the discovery of uranium fission. However, the German government was slower to respond to this information than the U.S. government.

So, German nuclear scientists proceeded with their own research. They formed a Uranium Society (Uran Verein) which was an informal scientific group. These men exchanged information about their research but kept it a secret from outsiders. Army Ordinance had a scientific team working on this problem but it was under the leadership of a second-rate physicist.

The best qualified groups were the Kaiser Wilhelm Institute (KWI) for Physics at Berlin (under Nobel Prize Laureate Werner Heisenberg) and the KWI for Medical Research at Heidelberg (under Walther Bothe). These groups had building space but money was not readily available from the government. Each academic research group had to find its own sponsor so the competition between the various research groups was very intense.

W. Bothe did studies on the properties of pure graphite. He found that graphite was not a suitable moderator. This was an unfortunate error for the Germans. They now had to rely on heavy water for their moderator. But the llied bombing and sabotage of the Norweigan hydro-plant kept their heavy water supply quite low. At one point they barely had enough heavy water for one experimental group and there were at least two groups. There was a need for an organization.

So, the uranium research conducted by the military

(Army Ordinance) was placed under the control of the Ministry of Education (Minister Bertrand Rust). It was governed by the Reich Research Council under an incompetent administraior and a second-rate chemist name Rudolph Mentzel. He was a brigadier in Himmler's SS (State Security Police), but as a scientist he left much to be desired. His position was similar to the one held by James B. Conant in OSRD (Conant was responsible for all science research for military use), but, as one scientist wrote, "The comparison ends there."

In early 1942, the Uranium Society thought that it was necessary to call the project to the attention of the highest members of government and military organizations. A special meeting was called and all top-ranking officials were invited. Invitations were sent to Speer, Keitel, Himmler, Raeder, Goering, Bormann, etc.--the top men in Hitler's regime. However, a secretary had sent them the three-day agenda instead of the agenda for the one meeting. When Himmler, Marshal Keital, and Admiral Raeder received the agenda they declined the invitation because of more pressing business.

So the meeting began without the presence of most of the important men of government. While the U.S. government was taking increased interest in nuclear research and was preparing to place it under the control of the U.S. Army, the NAZI government was pre-occupied with her victories and was not concerned with the needs of the uranium project. In addition, all uranium research was now under civilian control.

In the summer of 1942, Hitler put the Reich Research Council under Hermann Goering (Commander of the Air Force--a NAZI top brass). The German Air Force under Goering had developed a respectable research group. Hitler was hoping that Goering could do the same thing for all scientific research. But things did not go according to Hitler's plans. The new Reich Research Council was controlled by Goering's "presidential council." It consisted of 21 high-ranking military officers and party leaders, but no scientists. Professor Mentzel remained the active head of the Reich Research Council. So, very little change came as a result of this reorganization.

Professor Abraham Esau was put in charge of the uranium research, but he could not get the program moving any faster. So Esau was replaced by Walther Gerlach, a first-rate physicist and organizer (mid-1943). His task was to unite the two principal research groups--Kaiser Wilhelm Institute's and the former Army Ordinance Group--into one cooperative group.

However, Gerlach was faced with a new problem. Allied bombing threatened the laboratory facilities and forced the scientists to evacuate. They had to leave well-equipped laboratories in the cities and seek shelter in rather primitive quarters in various small villages spread all over Germany. When the Alsos Mission finally rounded up all the scientists, they found that the Germans were still in the laboratory stage in the development of atomic piles.

The German scientists claimed that they purposely delayed the progress of uranium research. However, they tried to make several chain reactions but failed (an atomic pile at KWI for Medical Research exploded--a regular gas explosion--and the building burned down). When the German scientists were captured they freely discussed their work. They offered to give us assistance with our work. Then we bombed Hiroshima. The German scientists did not believe the radio reports of the bombing of Hiroshima. They were certain that the radio broadcasts were part of a hoax. When they received further information, they became convinced that the U.S. did indeed possess an atom bomb. It was at this point that the German scientists started to discuss the moral issue. After Hiroshima, these scientists stated that it was immoral to use such a weapon and that they did not try to perfect an atom bomb.

However, Goudsmit and the Alsos Mission came to their own conclusions about the German failure. They had contacted all key scientists and examined all available German documents. From these sources they pieced together several reasons for the German failure. According to Goudsmit the reasons were:

> 1. The German scientists seemed to have lacked the vision. They did not believe in success from the very beginning....
>
> The German line of thought was as follows:
>
> a. An energy-producing uranium engine [reactor] is more likely to succeed than a bomb. In fact, they had entirely abandoned the hope of making a bomb during this war [WWII].
> b. An atomic bomb is a uranium engine which gets out of control; therefore, the road towards a bomb leads via the construction of the uranium engine [reactor].
> c. To make a bomb of pure plutonium never entered their minds, or at least was not considered feasible and not taken seriously. The idea of using a pile to produce plutonium and make a bomb out of that material came to them only slowly, after the detailed radio descriptions of our bomb in August 1945.
> d. A uranium engine is just as important as a bomb because it will make Germany economically self-supporting by the enormous power it may produce.
>
> As a result they concentrated their efforts on the production of atomic energy, and all the work done was nothing else but trying to build what is called over here a pile, a uranium machine.
>
> 2. Another reason why the Germans did not make any real progress was the key men in administrative positions were utterly incompetent....Army Ordinance had as its chief adviser on military matters Dr. Erich Schumann (a second-rate physicist). The scientists that worked for him were inferior compared

> with the scientists who were available in Germany for such a project....
>
> 3. They (the scientists) were seriously handicapped by the lack of prestige which science had in Germany (during Hitler's time). When war broke out, all German scientists were drafted.... Only when the war went bad,...were scientists released from the armed forces and put back on war work.... (10-2)

According to Goudsmit, key German scientists stated that the fundamental sciences were declining in Germany. They blamed the decline primarily to the lack of support for science. The loss of scientists due to NAZI persecution and to a greater extent, their replacement by incompetent party members instead of good scientists, led to the German decline.

The remarkable thing about the German scientists was their belief in supremacy. Throughout the war they believed that they were ahead of the Allies in uranium research. When the top scientists were captured they volunteered to cooperate on uranium research. They talked freely of their failures, because they believed they were pioneers in this field. When the first atom bomb was dropped on Hiroshima, the Germans finally realized that they were not ahead.

The German effort was small compared to the program followed by the Allies. The total expenditure was equivalent to about ten million dollars whereas we spent about two billion dollars on our program. The Germans used about 100 scientists on this project. But they were divided into small groups working on different parts of the problem and were spread all over Germany.

So the Germans, confident of their lead, worked at a snail's pace to develop the use of atomic energy. In contrast, the United States and their Allies were working very rapidly toward the solution of this problem. The motivation of the two groups was different. As one scientist stated,

> The fear of Hitler's defeat for German scientists was not as great as the fear of Hitler's victory by the allied scientists. (10-18).

But Hitler was defeated. What affect did Hitler's defeat have on the Allied bomb project? Let's take a look.

The Decision to Use the Bomb

The threat of a German atomic bomb had passed. Germany was defeated. The Allies did not fear a Japanese atomic weapon. Japan had good nuclear scientists but she did not have a supply of fissionable material. So the urgency for the development of an atom bomb should have decreased. But it did not! The timetable for the construction and testing of the weapon was kept intact. In fact, the completion of all parts for the first test were completed slightly ahead of schedule. The recommendation to use the bomb against Japan was already being debated.

After the first atomic bomb test a large number of scientists became concerned about its implications. They began to realize the political, military, and moral implications of atomic energy. But some scientists had given a great deal of thought to these implications long before the first successful test.

As early as 1943, a group of scientists, whose primary research had been completed, spent much time discussing the question. They realized that the bomb was a device which would be an ideal weapon for total war, surprise attack, and aggression. Many believed that once the atomic bomb was proven feasible, other nations could also develop them. They, as individual scientists and groups of scientists, addressed themselves to this problem.

The Bohr Memorandum

The first scientist to contact President Roosevelt was the "father of atomic physics," Niels Bohr. While at Los Alamos, he discussed the implications of atomic energy at length with Oppenheimer, Teller, and other younger associates. He was concerned about the future. In 1944 he presented President Roosevelt with a memorandum which summarized his thoughts. Bohr's memorandum touched on the following points:

(1) Atomic energy would "revolutionize industry and transport" and would "completely change all future conditions of warfare."

(2) This wartime research was only the beginning and research "continually revealed new possibilities."

(3) The advantage gained by a possession of atomic weapons would be "outweighed by a perpetual menace to human security."

(4) That, in an age where science has already harnessed atomic energy and would continue to create new means of military power, openness, and atomic energy control were the only guarantees of security and a lasting peace.

Bohr was optimistic about the possibility of nations accepting openness and international control of atomic energy. He felt that nations would realize that they had more to gain from peaceful uses of atomic energy than from military uses. Bohr's statements did not have any effect on Roosevelt but it did and continues to have, an influence on scientists.

Szilard Letter

In March, 1945 Dr. Leo Szilard, who had helped alert

Roosevelt in 1939, sent a letter to Roosevelt via Secretary of State James Byrnes. This letter predicted with great foresight the effect atomic energy would have on international relations, in particular Russian. In this letter, which refers to the first atomic bombs to be perfected, he states:

> These bombs will be much less powerful than the ones we now know can be made,...yet the first bomb that is detonated over Japan will be spectacular enough to start a race in atomic armaments between us and other nations....
>
> For a few years after that, we shall almost certainly be ahead of Russia. But even if we assume that we could keep ahead of her in this development all the time, this may neither offer us protection from attack nor give us substantial advantage in case of war.
>
> ....
>
> One of the questions that has to be considered is whether it might be possible to set up some system of controls of the production of these [fissionable] materials. Whether it is politically and technically feasible to set up effective controls, and what we could do to improve our chances in this respect, are questions that urgently require study and decision.
>
> As to our chances of persuading the Russians to accept mutual control, much may depend on the proper timing of our approach to Russia; it would appear that such an approach would have to be made <u>immediately after we demonstrated the potency of atomic bombs</u>. (10-3)

Szilard insisted that only an international control agreement could prevent an arms race. However, Roosevelt did not get a chance to read it. The letter was on his desk the day the President died (April 12, 1945). Szilard attempted to get the letter to President Truman, but his efforts failed.

The Franck Report

Several weeks later (June, 1945) a group of scientists sent Secretary Stimson a special report. This group of scientists--known as the Committee on Social and Political Implications--was headed by James Franck (a German refugee physicist). The committee included such men as Leo Szilard, Eugene Rabinowitz, and Glenn C. Seaborg.

It was similar to Bohr's and Szilard's point of view, but it was more forceful. In the preamble these scientists state:

> The scientists on this project do not presume to speak authoritatively on problems of national and international policy. However, we found ourselves, by the force of events during the last five years, in the position of a small group of citizens cognizant of a grave danger for the safety of this country as well as for the future of all the other nations, of which the rest of mankind is unaware. We therefore feel it our duty to urge that the political problems arising from the mastering of nuclear power to be recognized in all their gravity, and that appropriate steps be taken for their study and the preparation of necessary decisions. (10-4)

The authors of the Franck Report believed that the

United States was not committed to the use of the bomb. They considered it a device for deterring its use by other nations. They state:

> The compelling reason for creating this weapon with such speed was our fear that Germany had the technical skill necessary to develop such a weapon and that the German Government had no moral restraints regarding its use. (10-5)

They ruled out the actual bombing of Japan, but they suggested two alternatives. One, give a demonstration in some uninhabited region or two, continue to keep the weapon a secret and let someone else use it first. They recommended that the government should consider the alternative that:

> The benefit to the nation, and the saving of American lives in the future, achieved by renouncing an early demonstration of nuclear bombs and letting the other nations come into the race only reluctantly, on the basis of guesswork and without definite knowledge that the 'thing does work,' may far outweigh the advantages to be gained by the immediate use of the first and comparatively inefficient bombs in the war against Japan. (10-6)

They were recommending that the United States give up the benefit of a temporary military advantage in favor of preventing a nuclear arms race. To them, the <u>temporary benefit did not outweigh</u> a certain <u>future risk</u>.

This report caused much concern within the government. The scientists at the various atom bomb production sites were polled. A slight majority favored the use of the bomb against Japan. The final decision was not an easy one but it had to be made.

The Interim Committee

On March 15, 1945 Secretary of War Stimson held a conference with President Roosevelt. They discussed various aspects of the Manhattan Project. Stimson urged the President to seriously consider the two schools of thought about the control of atomic energy: (1) U.S., Britain, and Canada keep control; or (2) international control. Stimson felt that Roosevelt had to make a decision before the first bomb was used.

The Secretary never saw Roosevelt alive again. Harry S. Truman--elected Vice-President in 1944--was now President of the United States. At his next White House visit (April 25, 1945), Stimson informed President Truman about the secret project. This was quite an ironic situation. As one author explains:

> Only a few months earlier, Senator Truman had been chairman of a committee investigating the national defense program. Word had come of huge expenditures for plants in Tennessee and Washington state, and Truman was anxious to find out why so much money was being spent without any official explanation to Congress.
>
> Stimson had summoned Truman and told him that the project was top secret; many people engaged in it did not even

> know what they were producing. A Congressional investigation, Stimson hinted, would be a serious breach of security. That was all Truman needed to know, and the investigation was promptly called off. (10-7)

Now, as President, Truman was officially informed about the Manhattan Project.

The Secretary's report took into consideration all aspects of the new weapon. Points pro and con were presented, but according to Stimson, they never questioned the use of this nuclear device. As he stated in 1947:

> At no time, from 1941 to 1945, did I ever hear it suggested by the President, or by any other responsible member of the government, that atomic energy should not be used in the war....It was our common objective, throughout the war, to be the first to produce an atomic weapon and use it. The possible atomic weapon was considered to be a new and tremendously powerful explosive, as legitimate as any other of the deadly explosive weapons of modern war. The entire purpose was the production of a military weapon; on no other ground could the wartime expenditure of so much time and money have been justified... (10-8)

The report recommended a select committee. This committee--appointed by Truman and called the Interim Committee--consisted of eight members (politicians, businessmen, and two scientists) and a panel of four first rank nuclear scientists (A. H. Compton, Enrico Fermi, E. O. Lawrence, and Robert Oppenheimer). They had two main responsibilities: (1) advise the President on various questions related to atomic energy; and (2) recommend how the new explosive device was to be used. In other words, they were to consider the implications of atomic energy in wartime and peacetime. They did not have too much time to decide because the atom bomb was to be ready in late summer of 1945.

Careful deliberation of possible alternatives ranged from a technical demonstration to an unannounced use on Japan. According to some committee members. a technical demonstration might prove to be a dud. It would completely ruin our chances of impressing the Japanese leaders. The committee felt that ending the war was the most important goal and that the best way was the military use of the nuclear weapon.

On June 1, 1945 the interim committee unanimously adopted the following recommendations:

> 1. The bomb should be used against Japan as soon as possible.
> 2. It should be used on a dual target--that is, a military installation or a war plant surrounded by, or adjacent to, houses or other buildings most susceptible to damage.
> 3. It should be used without prior warning [of the nature of the weapon].
>
> (One of the committee members later changed his vote on this recommendation.) (10-9)

The Interim Committee considered other suggestions (such as the Franck Report), but it did not change its recommendations. The scientific panel commented as follows:

> The opinions of our scientific colleagues on the initial use of these weapons are not unanimous: they range from the proposal of a purely technical demonstration to that of the military application best designed to induce surrender. Those who advocate a purely technical demonstration would wish to outlaw the use of atomic weapons, and have feared that if we use the weapons now our position in future negotiations will be prejudiced. Others emphasize the opportunity of saving American lives by immediate military use, and believe that such use will improve the international prospects, in that they are more concerned with the prevention of war than with the elimination of this special weapon. We find ourselves closer to the latter views; we can propose no technical demonstration likely to bring an end to the war; we see no acceptable alternative to direct military use. [my italics] (10-10)

The Interim Committee played an important role. However, its recommendations were only advisory. The final decision had to be made by President Truman who still had about two months before the bomb was perfected. Truman conferred with U.S. military leaders and Prime Minister Churchill. They all were in favor of the bomb's use.

On July 24, 1945 Truman told Stalin about the new weapon. According to Truman:

> Stalin showed no special interest. All he said was that he was glad to hear it and hope that we would make 'good use of it against the Japanese.' [Actually, Stalin knew about the Manhattan Project before Truman. He was informed by a few scientists--spies involved with the atom bomb project.] (10-11)

So, on that day Truman gave the tentative okay for the use of the weapon. He instructed General Carl Spaatz (Commander of U.S. Army Air Forces - Pacific) to drop the bomb on Japan as soon after August 3rd as weather permitted.

Actually, the Japanese leaders helped Truman make his final decision. On July 26, 1945 Truman, Churchill, and Chiang Kai-shek (leader of China) presented the Potsdam Declaration (Russia was not at war with Japan at that time and did not participate in the official announcements). This document offered Japan the choice between surrender and hope for an honorable future and "inevitable and complete destruction." On July 28, 1945 the Japanese government issued a statement to its people which the Allies interpreted as a rejection of the Potsdam Declaration. Truman gave final authorization on August 2nd and the rest is public history. Stimson wrote about this decision as follows:

> The decision to use the atomic bomb was a decision that brought death to over a hundred thousand Japanese. No explanation can change that fact and I do not wish to gloss it over. But this deliberate, premeditated destruction was our least abhorrent choice. The destruction of Hiroshima and Nagasaki put an end to the Japanese war. It stopped the fire raids, and the strangling blockade; it ended the ghastly specter of the clash of great land armies.
>
> In this last great action of the Second World War we were given final proof that war is death [italics mine].

> War in the twentieth century has grown steadily more barbarous, more destructive, more debased in all its aspects. Now, with the release of atomic energy, man's ability to destroy himself is very nearly complete. The bombs dropped on Hiroshima and Nagasaki ended a war. They also made it wholly clear that we must never have another war. This is the lesson man and leaders everywhere must learn, and I believe that when they learn they will find a way to lasting peace. There is not other choice. (10-12)

The Fate of Two Cities

Hiroshima

On August 2, 1945 the following orders were cut:

> 20th Air Force attack targets in Japan on 6th August. Primary target... Hiroshima...

The 509th Composite Group (of the 20th Air Force) had unknowingly been practicing for this mission. They were dropping replicas of the new weapon but these so-called "Pumpkins" (orange-colored) used only TNT. Tokyo Rose (Japanese radio propagandist) ridiculed the 509th. In a broadcast to the U.S. she said:

> You are now reduced to small missions of three planes and the bombs they drop are just duds. (10-13)

The day before the mission the men of the 509th were told the secret of the Pumpkins. They were then briefed on their missions. The first raid consisted of seven B-29's. The first three planes were weather planes which flew over the target areas (Hiroshima, Kokura, and Nagasaki). Hiroshima, a large sea port, army base, and industrial center was the primary target. Kokura and Nagasaki were secondary and tertiary targets. Three more planes took off one hour later (the seventh plane was held in reserve). In the second group of planes was the Enola Gay (piloted by Colonel P. W. Tibbetts, Jr.) which carried the uranium 235 gun barrel type atomic bomb. The plane carrying the "Little Boy" was joined by two observation planes. The historic log of the Enola Gay reads:

	(Monday 6th August)
0245	(2:45 A.M. Tinan Air Base Time) take off
0300	started final loading of gun
0315	finished loading
0605	headed for Empire from Iwo [Jima]
0730	red plugs in (detonators for explosives)
0915½	drop bomb
0930	mission successful (10-14)

The spectacle was described by Captain William S. Parsons (after his return) as follows:

> It was a terrific spectacle. The huge dust cloud covered everything. The base of the lower part of the mushroom, a mass of purplish-gray dust about three miles in diameter, was all boiling--the entire area was boiling. A huge white cloud got separated from the top of the mushroom and went upward. Then a second white cloud rose into the air and started chasing the first one. The mushroom smoke reached our altitude;

> then another mushroom came up, also very turbulent. There was also another column of smoke off to one side, different in character from the main mass, at a forty-five-degree angle from the ground. It looked as though it was coming from a huge burning fire, and seemed to settle back to earth again. The purple clouds and flames were whirling around. It seemed as though the whole town got pulverized. (10-15)

The results, as far as military standards go, were spectacular. Nearly 60 percent of the city's area had just about disappeared. About 80 percent of the buildings were destroyed by blast and fire. The Japanese officials later estimated that 71,000 people had been killed or were missing. Another 68,000 people had been wounded. A Japanese general sent to investigate the blast reported the following:

> ...there was but one black dead tree, as if a crow was perched on it. There was nothing but that tree. As we landed at the airport all the grass was red as if it had been toasted....Everything had burned up simultaneously...the city itself was completely wiped out. That must be the word, yes, completely wiped out.... (10-16)

U.S. planes dropped leaflets urging the Japanese people to surrender. However, the leaders of Japan were divided on this issue. One Japanese naval commander proposed mass suicide attacks--he was prepared to sacrifice millions of people in these attacks--against U.S. invaders. A less fanatical faction argued for the acceptance of the Potsdam ultimatum. Foreign Minister Togo argued that the war situation was hopeless, but the military was not convinced. The two groups were still arguing their positions on August 9th when Nagasaki was bombed.

Nagasaki

Unexplained coincidences have occurred throughout history, but few compare with the events of the second atomic bomb attack.

On June 16, 1945 Truman received the initial recommendations from the Interim Committee. He then ordered General Groves to select targets in Japan. Groves appointed a committee to make a list of tentative targets. The targets were picked because they met the following three criteria:

1. their destruction would have the greatest possible effect on the will of the Japanese to continue the war;
2. the targets should be military--important headquarters, troop concentrations, or production centers; and
3. the target should not have been bombed before.

The Target Committe selected four cities which met this criteria (Hiroshima, Kokura, Niijata, and Kyoto).

Kyoto is the ancient capital of Japan and is a city of temples with religious importance to the Japanese. So, with Stimson's advice, Truman scratched Kyoto from the list and replaced it with Nagasaki.

Hiroshima was the primary target on the first mission, but Kokura was the primary target on the second mission. Nagasaki was now the secondary target. The events of the second mission would make a good plot for a movie, but in this case it was a real event.

The second atomic bomb-carrying plant (Bock's Car) was delayed waiting for one of the other two escort B-29's. Finally, the pilot proceeded without it. When the B-29's reached Kokura the reported good visibility had changed. The winds had brought in clouds. The Bock's Car circled Kokura for 45 minutes but the weather remained bad. So the pilot headed for the secondary target, Nagasaki.

Nagasaki was also hidden by cloud cover. The delays had consumed almost all of the Bock's Car's fuel so the crew could only make one bombing run. As they prepared to bomb by radar the clouds opened up. The clouds had an opening so that Nagasaki could be seen by sight. The bombadier set the bombsight crosshairs on a race-track and the "Fat Man" dropped from the bomb bay.

The bomb exploded between two Mitsubishi armament plants--north of the true target. Casualties of 35,000 killed and 65,000 wounded were reported. Destiny had chosen Nagasaki and, like Hiroshima, it was destroyed by a single bomb.

The leaders of the Japanese government were arguing their positions when the bomb struck Nagasaki. The next day (August 10th) Emperor Hirohito was asked for his advice. He advised the acceptance of the Potsdam Declaration, but arguments for something other than unconditional surrender persisted. On August 14th, the Emperor again advised unconditional surrender. The next morning a group of Japanese Army officers attempted to "save" the Emperor. However, their plot failed. At noon the Emperor spoke to his people over the radio. He stated:

> ...the enemy has begun to employ a new and most cruel bomb, the power of which to do damage is indeed incalculable.... Should we continue to fight, it would not only result in an ultimate collapse and obliteration of the Japanese nation, but it would also lead to the total extinction of human civilization... (10-17)

Later that day Japan announced her willingness to surrender.

Postscript

On August 14, 1945 the Japanese accepted unconditional surrender. The people of the United States were overjoyed. The scientists at Los Alamos celebrated by igniting explosives, but their joy did not last long.

Scientists began to consider what their work had accomplished. They started the atomic bomb project as a deterrent against Germany but the United States was first to use it. We had exchanged roles with our NAZI enemies. The final decision had been taken out of the scientists' hands but they felt responsible. Scientific, military, business, and political leaders were all participants in the project and shared the responsibility. The use of atomic weapons is in part responsible for many of the international problems that exist today.

Were we correct in using the atomic bomb? That is a difficult question and there is no easy answer. It would be unscientific for us to answer a question without knowing all the conditions. We are looking at an event after it has occurred. Since we are not surrounded by the same conditions we cannot really judge the decision made by others.

However, most people agree on one conclusion: the utilization of atomic energy must be administered by rational and emotionally stable people. After Hiroshima and Nagasaki, scientists resolved that the use of atomic energy should be controlled.

Yet, how can the utilization of atomic energy be controlled? That is the question that science and society are debating. The scientific community is divided over the issue of control of atomic energy utilization. Includea in the disagreement, is the question of the control and use of nuclear weapons. What is the solution? Nobody knows for certain but it is a problem worth considering.

In the next section we will consider the scientist and his work toward a more sensible administration of atomic energy. We will look at some of the benefits and risks of using atomic energy, and the products of atomic energy and what they may have in store for the future.

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